MARCH 1960
Volume 194 Part 3

Established 1869
Incorporated by Royal Charter 1899

JOURNAL OF THE IRON AND STEEL INSTITUTE

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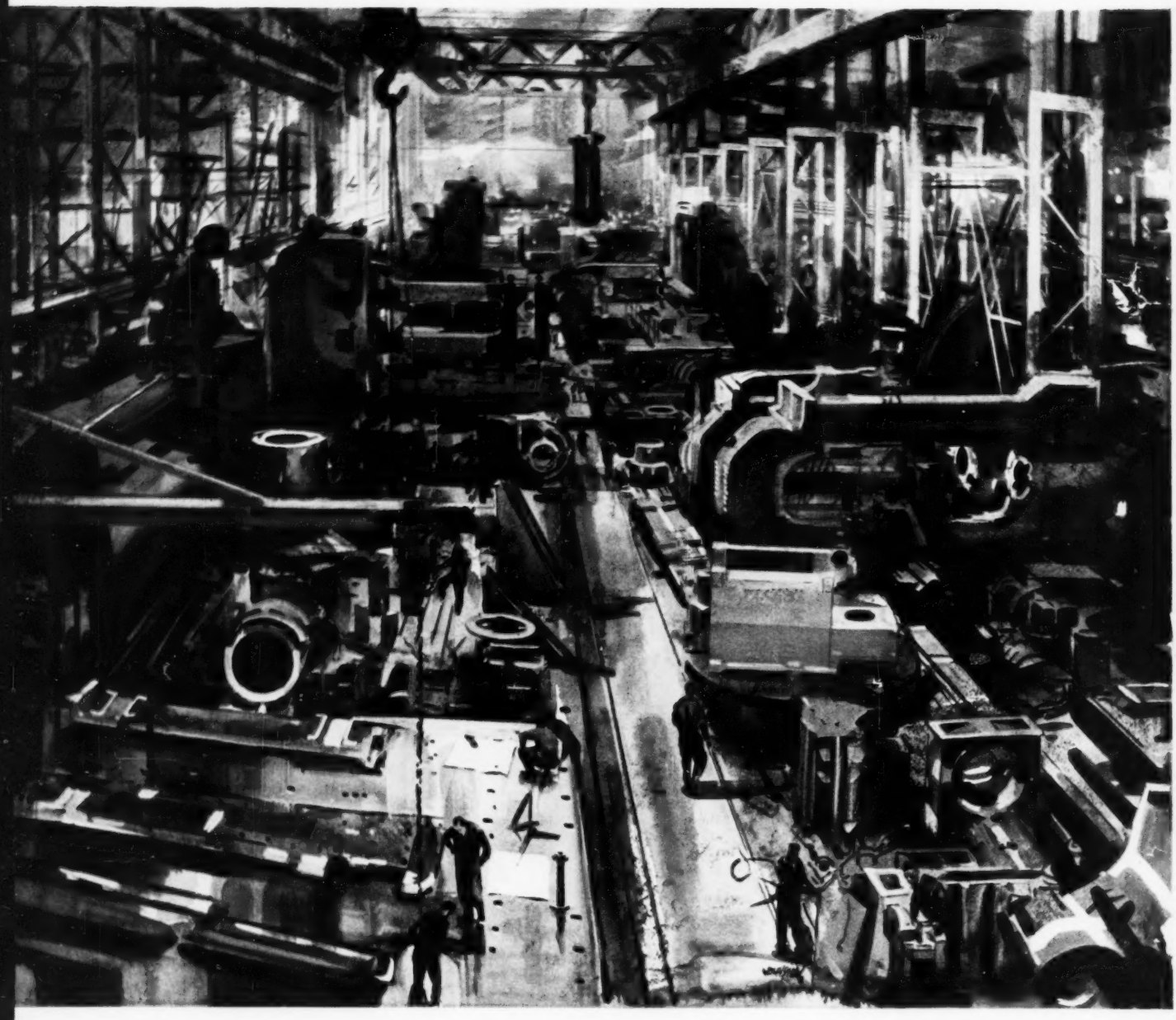
PALETTE ON PRODUCTION



No. 4 in a series of original paintings specially commissioned from Robert Johnston, R.I., S.M.A., to illustrate the productive capacity of Davy-United for metal works plant. This painting gives a typical impression of part of the heavy machining section of Darnall Works, in which single pieces up to 170 tons in weight are handled and tooled as everyday jobs.

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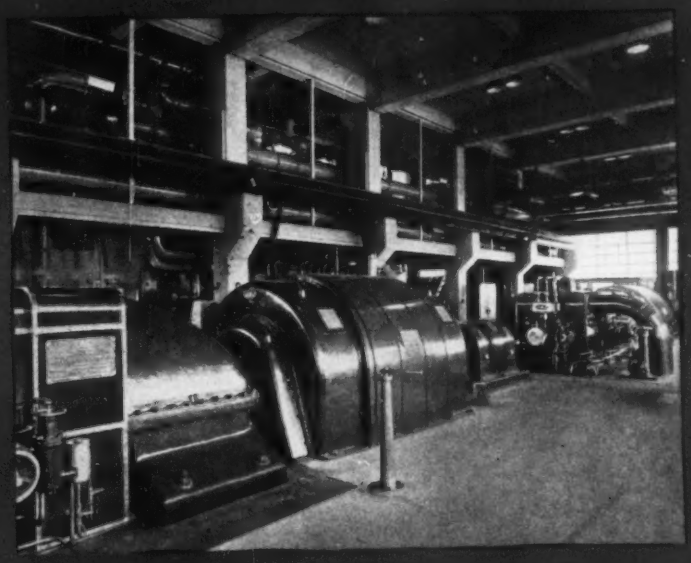
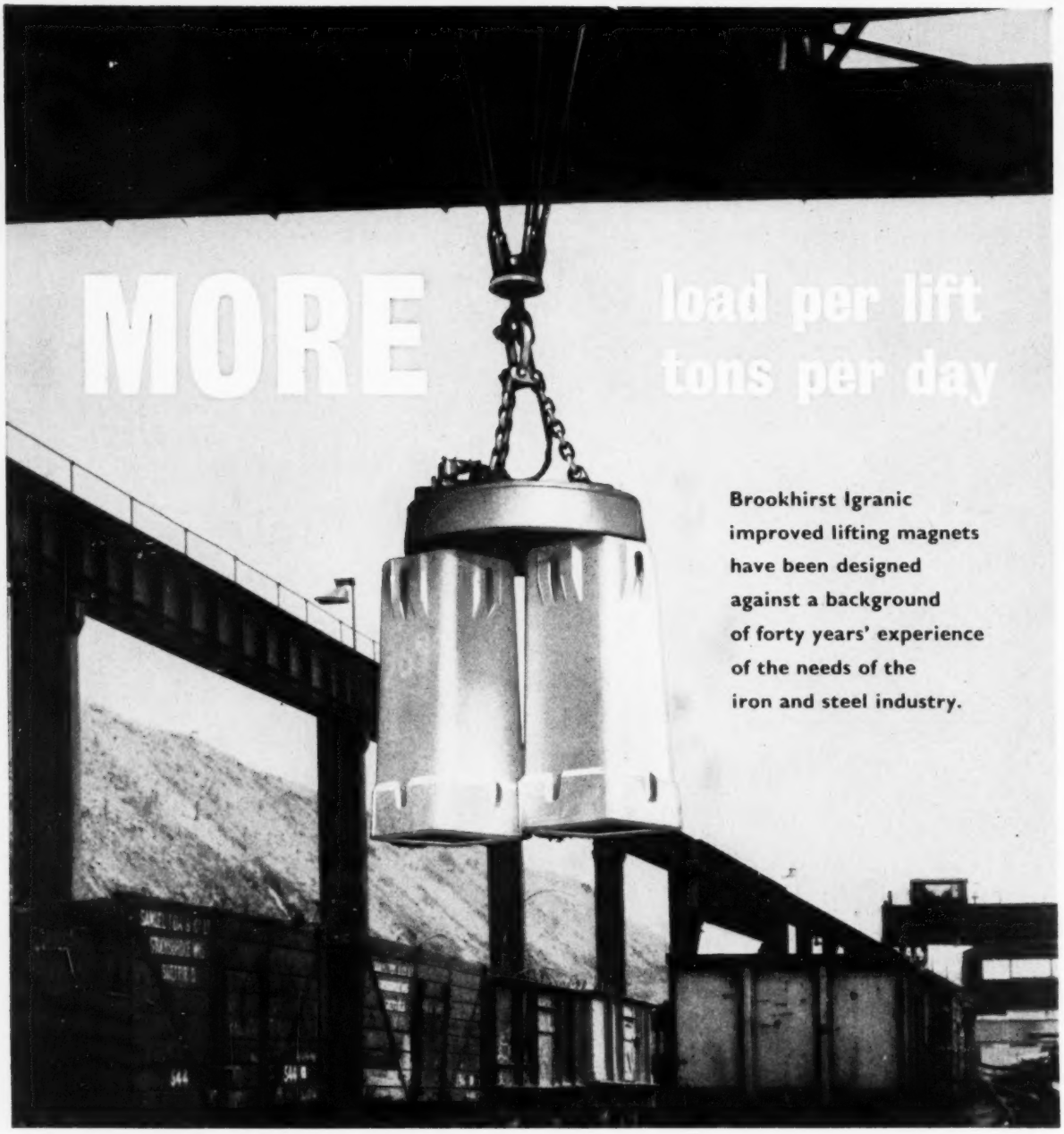


Above :- The turbo-alternators
Above right :- The boiler firing floor

A general view of the power station



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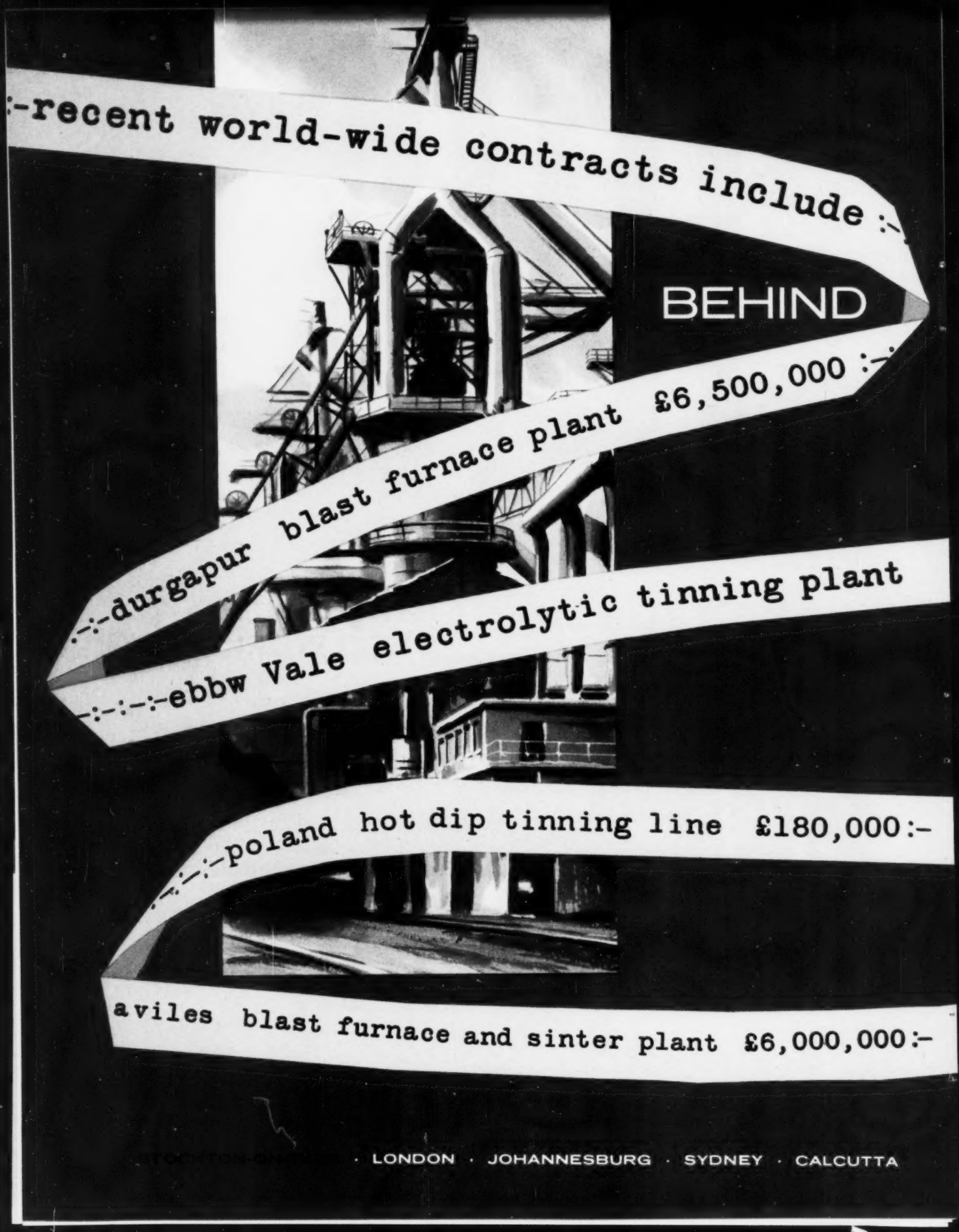
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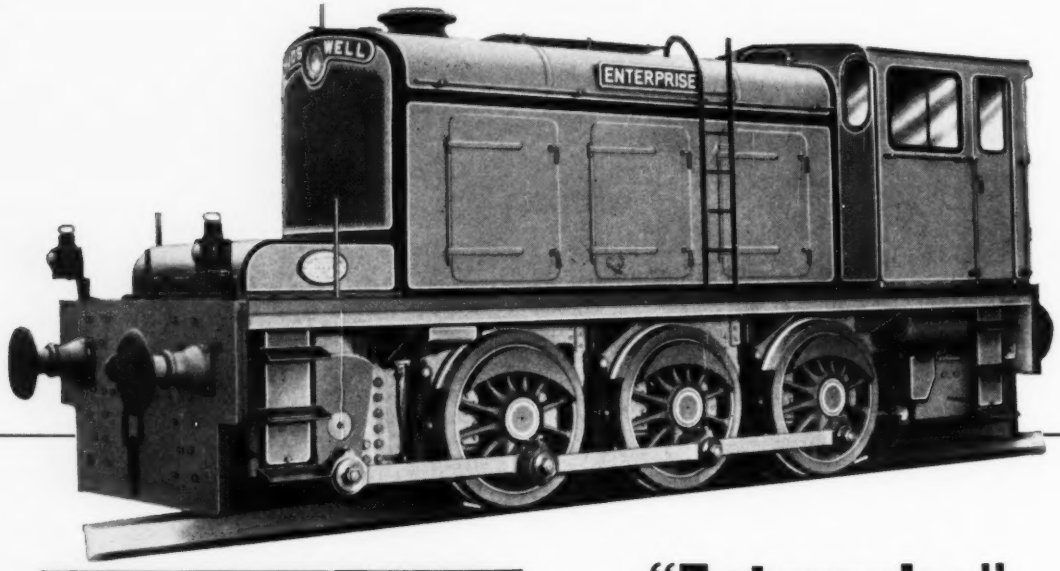

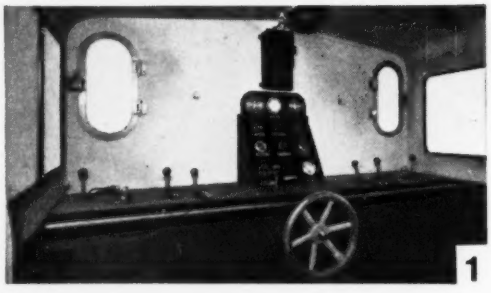

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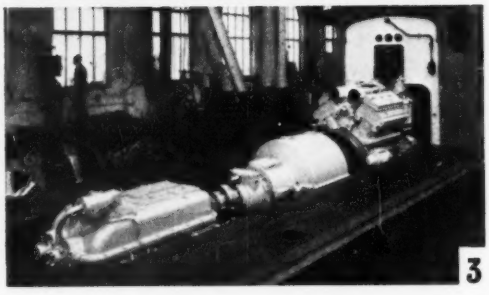

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3. *Installation in the locomotive 'Enterprise' showing left to right, the final reduction gearbox, the Dual Fluidrive transmission, and the Paxman V-6 pressure-charged constant h.p. engine.*

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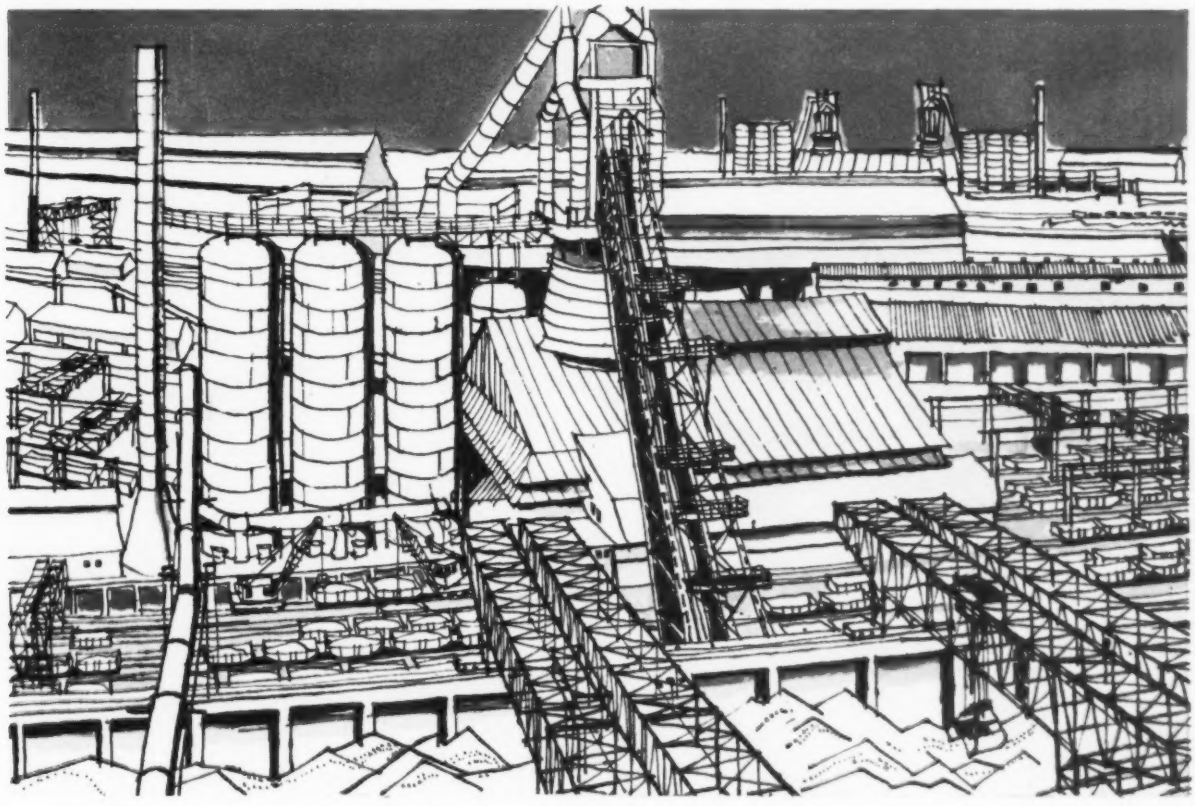

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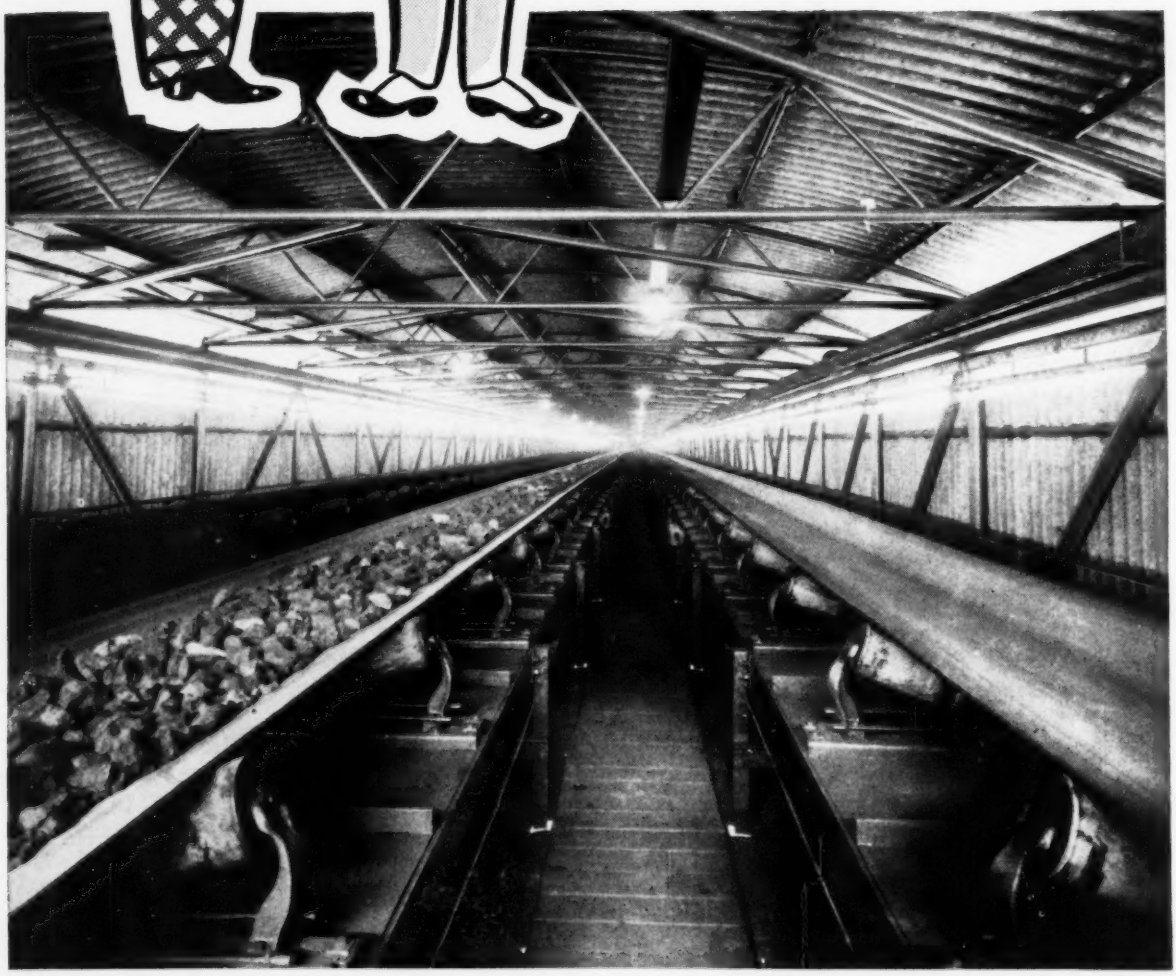

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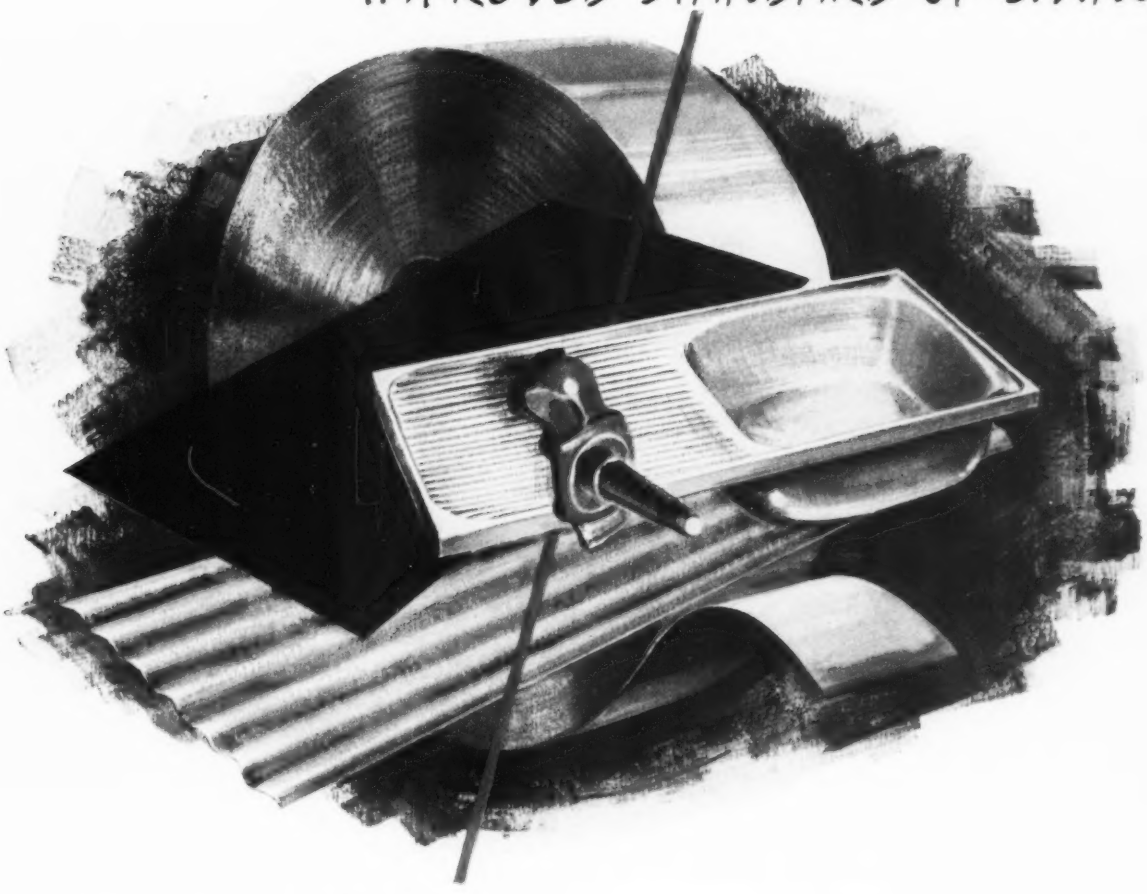

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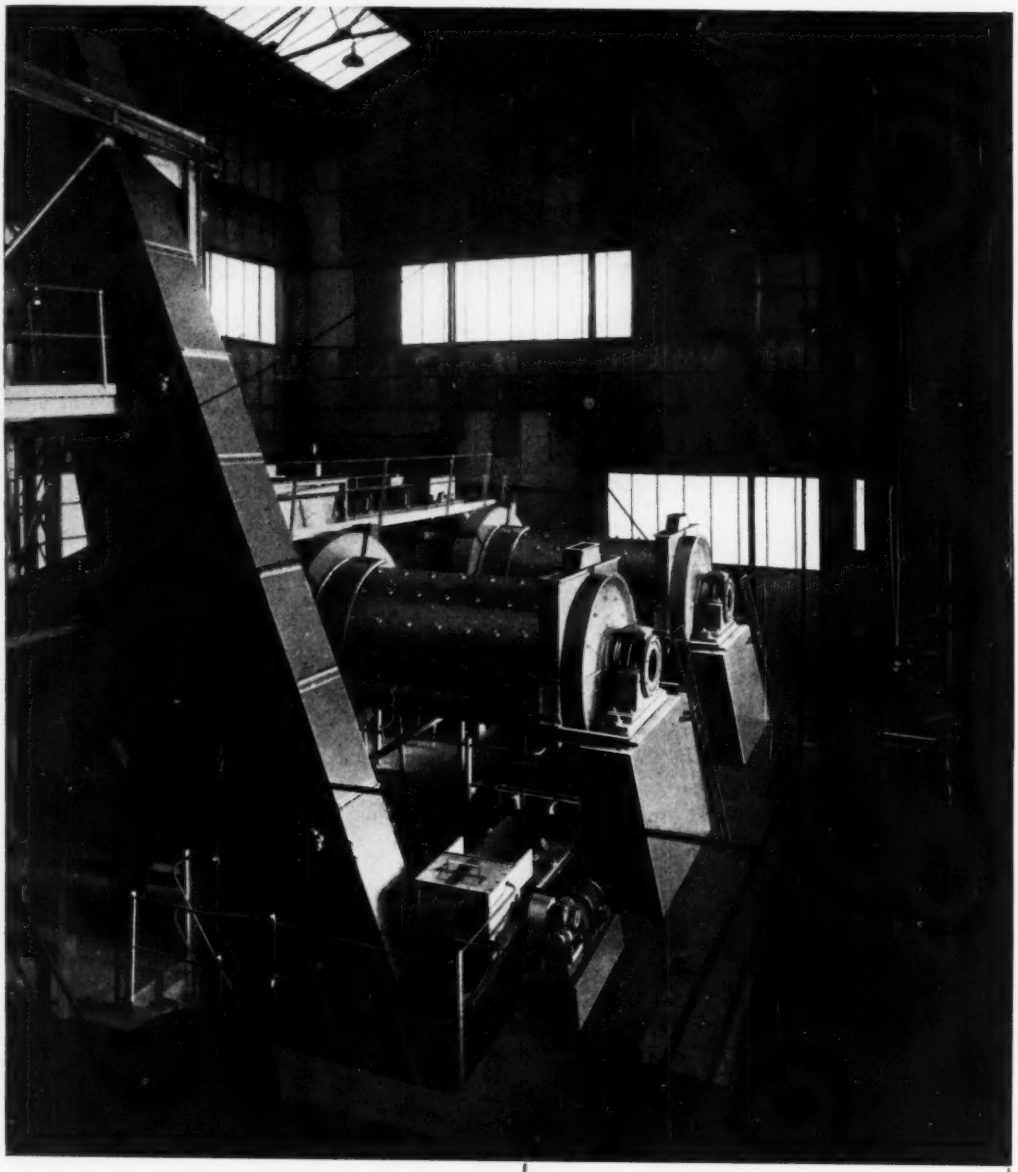

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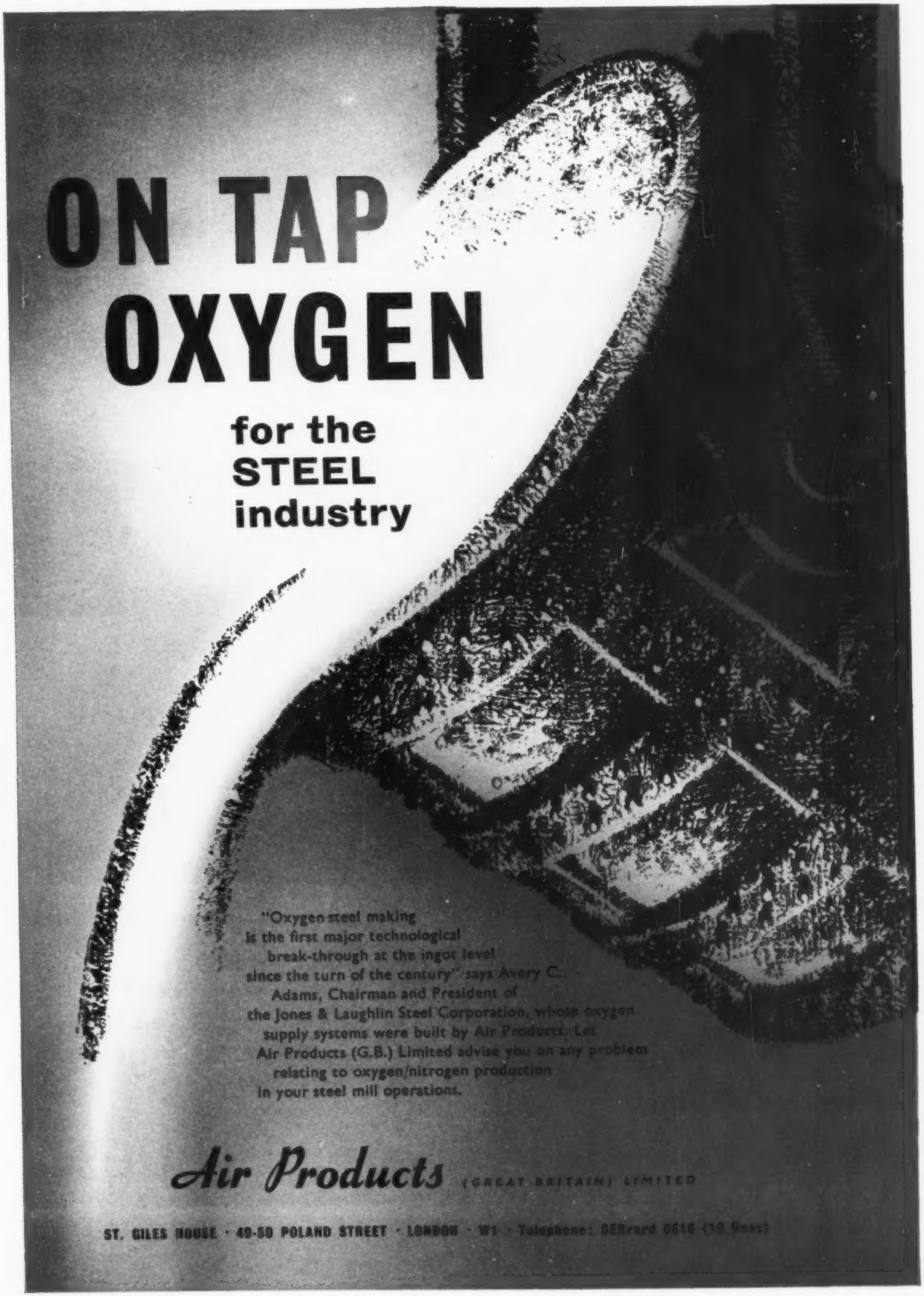
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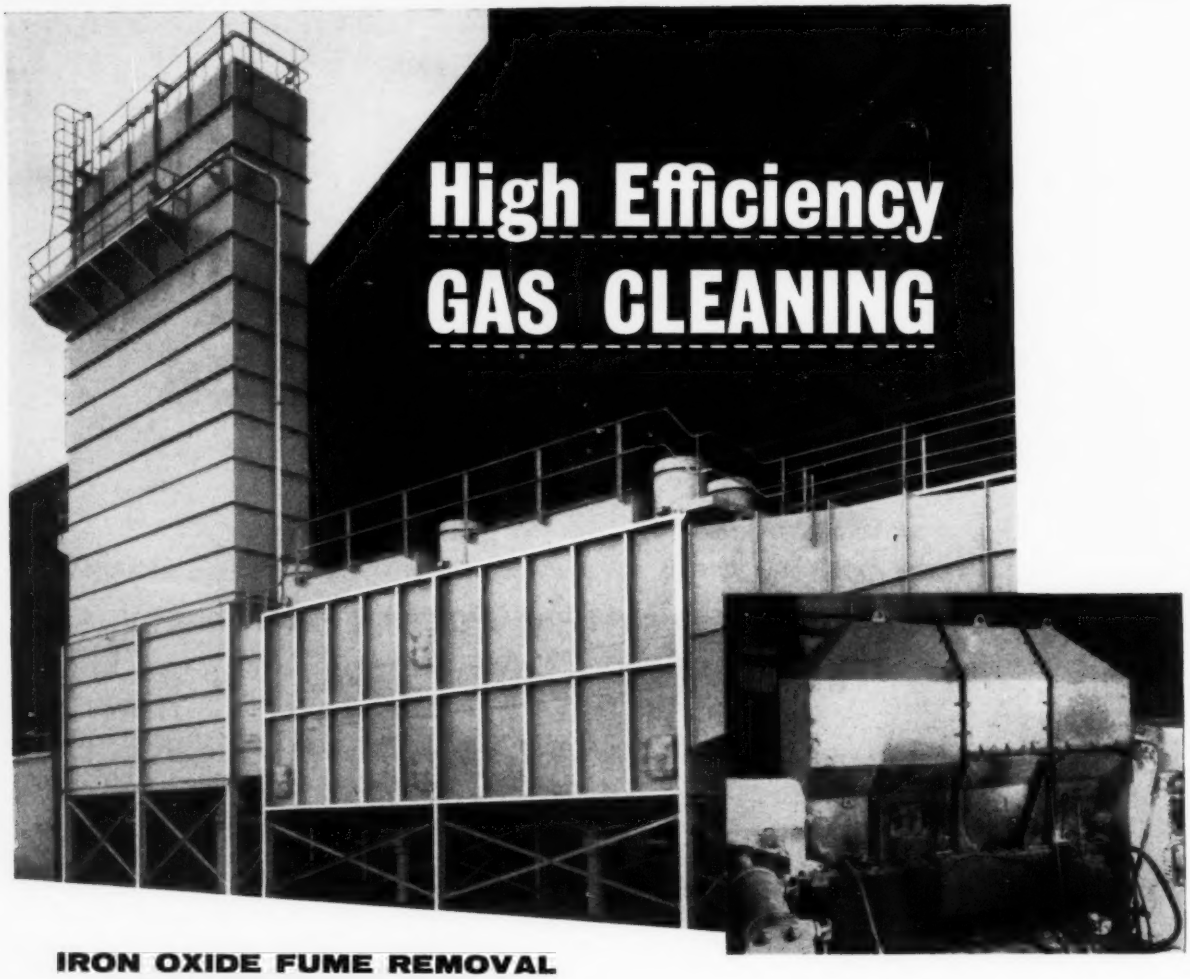

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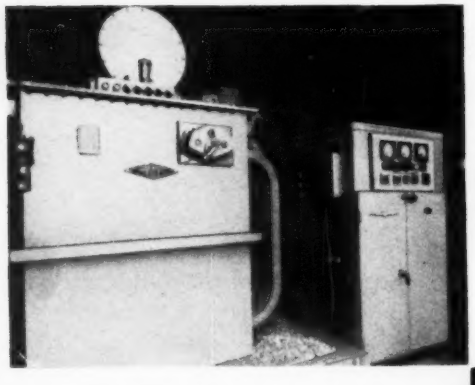
An irrigated Holmes-Elex Electrical Precipitator preceded by a gas storage/wash tower cleaning exhaust air from the deseaming plant at the Rotherham Works of Messrs. Steel Peech & Tozer (Branch of the United Steel Companies Limited). The photograph inset shows the exhaust hood enclosing the deseaming plant



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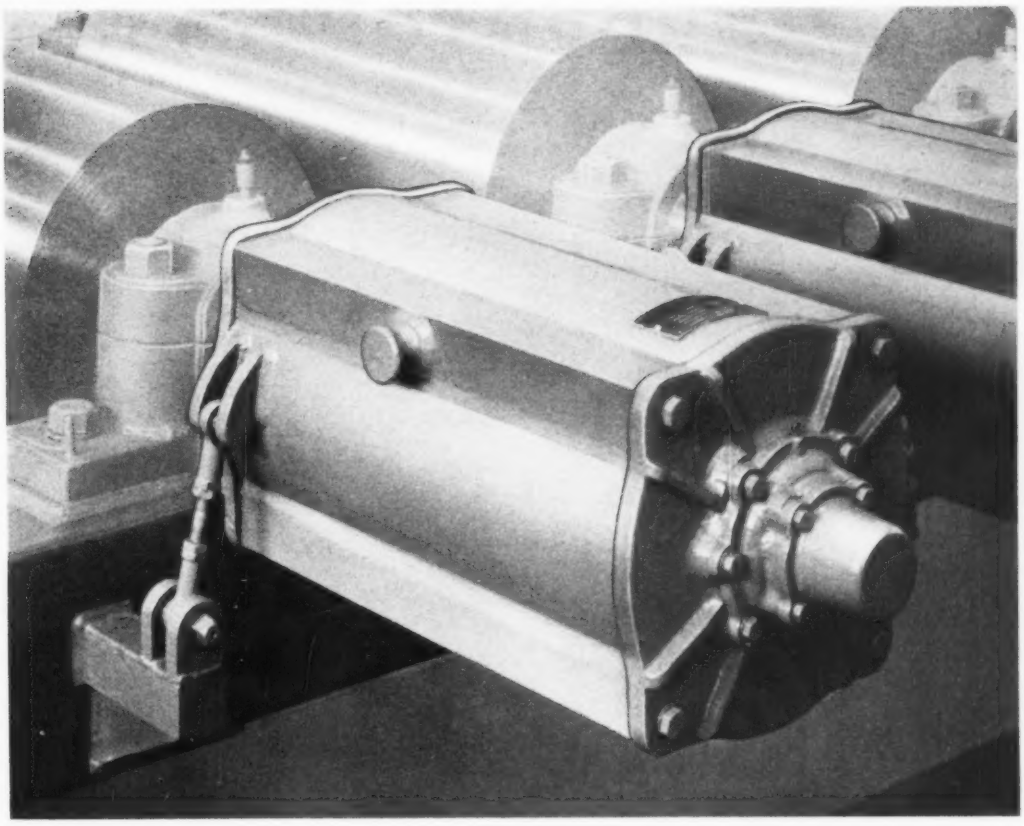

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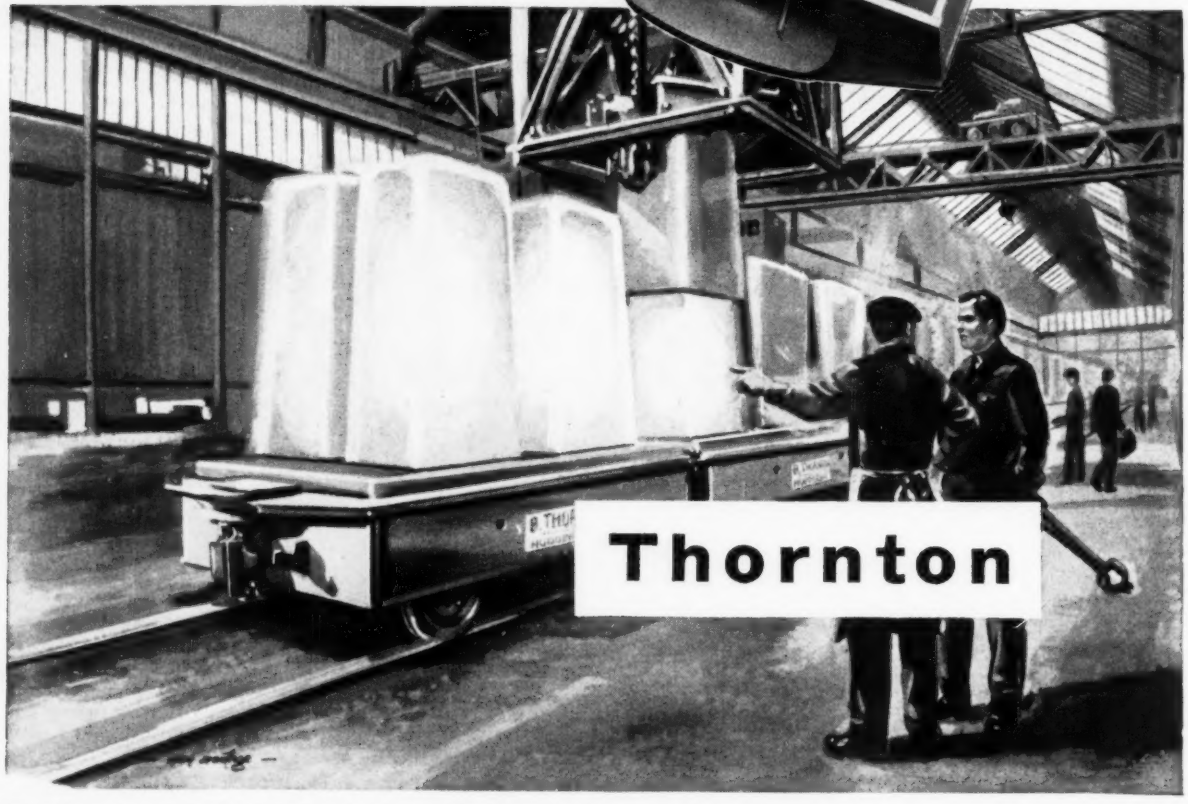

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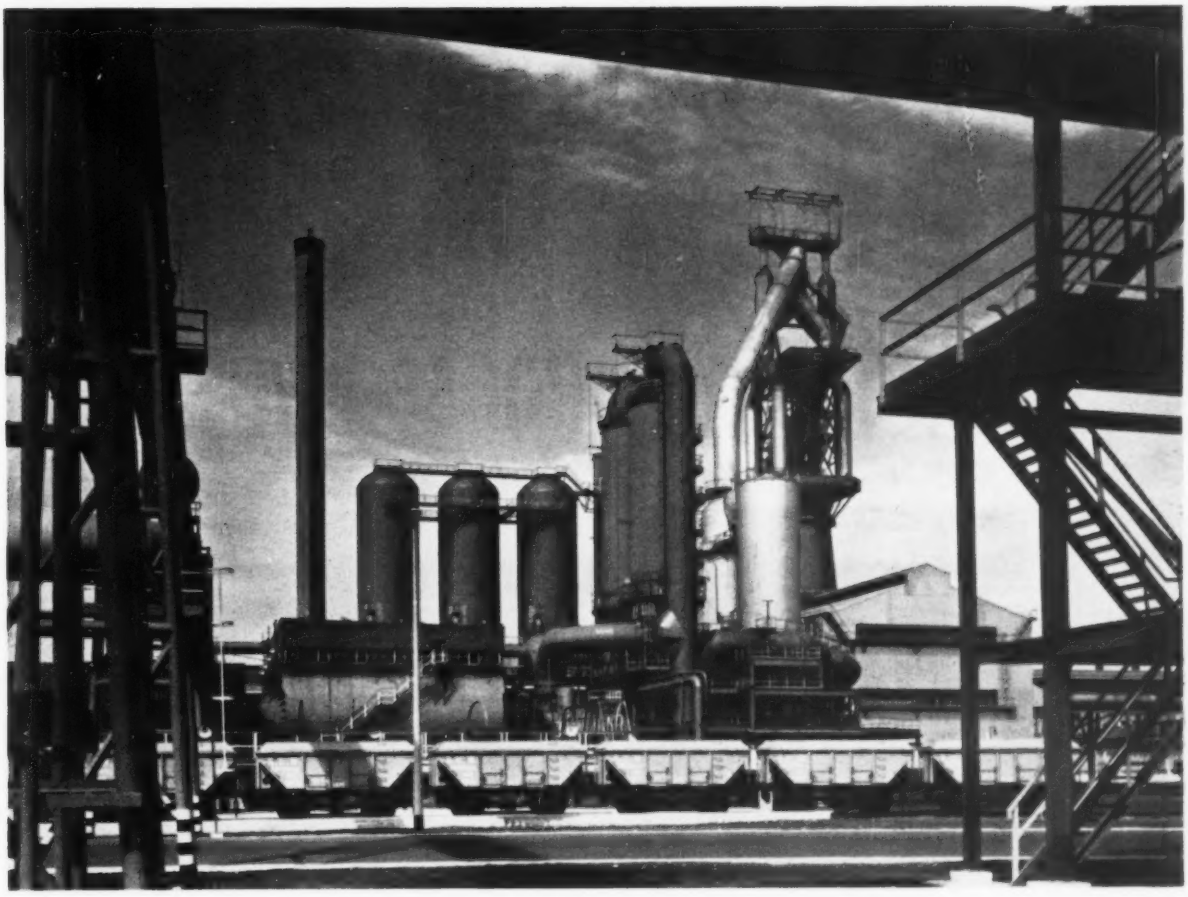

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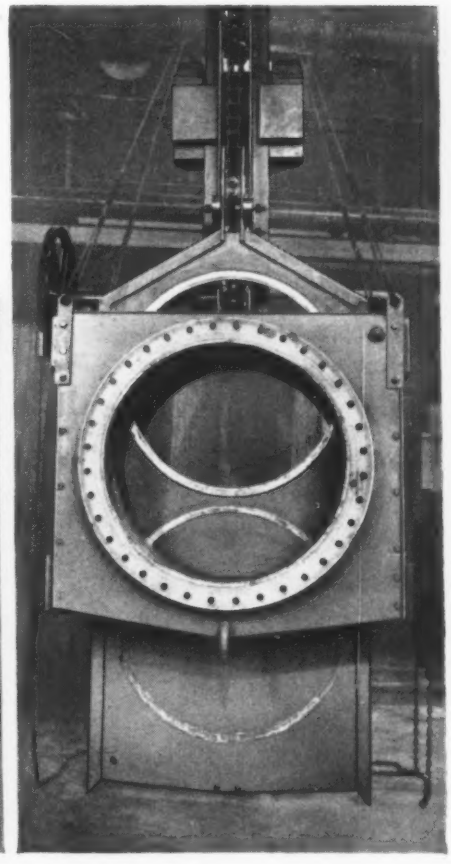

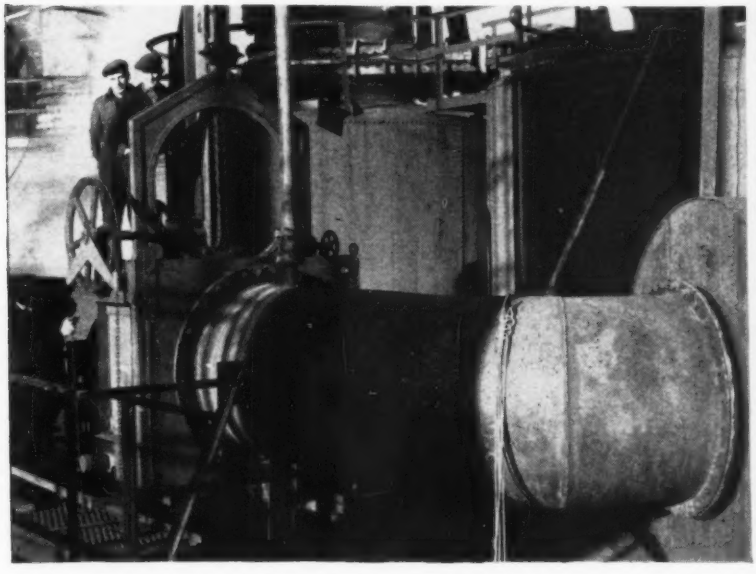

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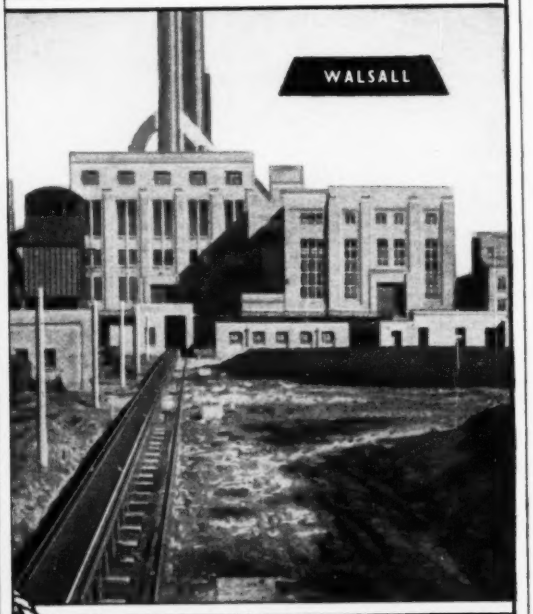

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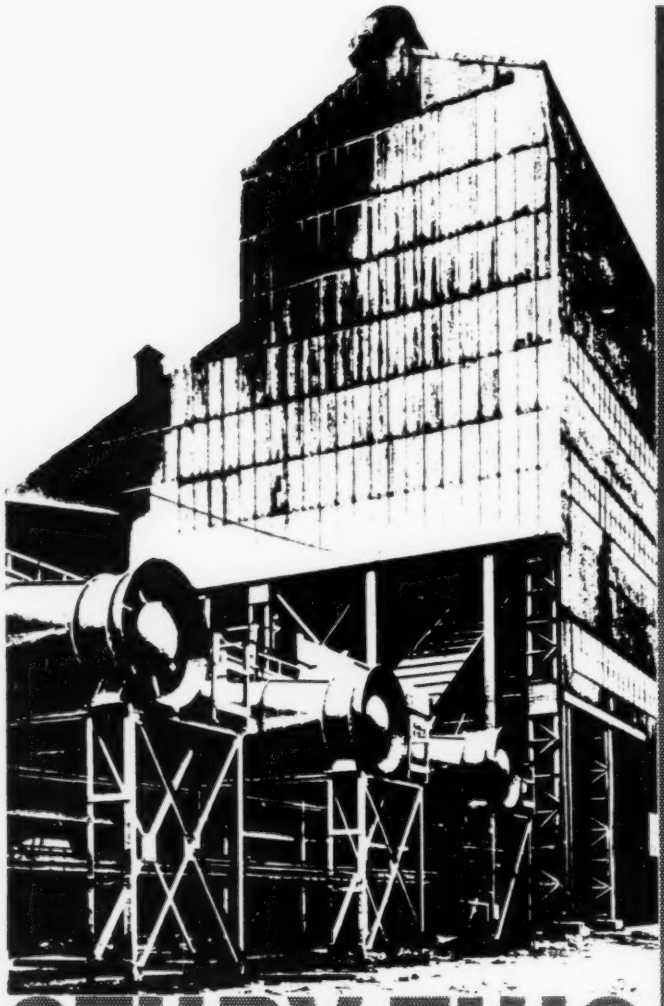
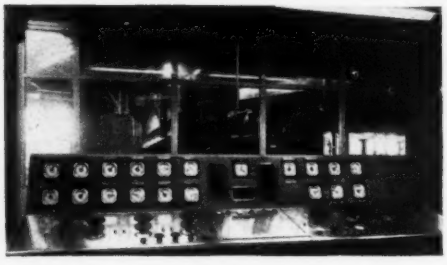
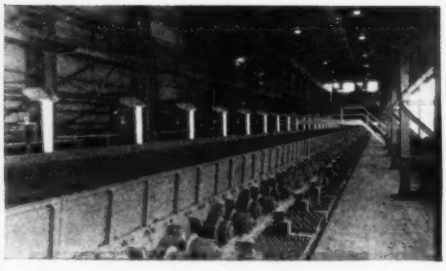


The Igniter



Sinter Process Control Desk



The Sinter Strand

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. . . for it is typical of the plants H.H. are building for steelworks at home and abroad.
Each plant is designed to make the finest high grade sinter by accurately proportioning the available raw materials. Careful design also ensures that running costs are reduced to a minimum whilst maintaining the quality of the sinter.

This plant was built for the Shelton Iron and Steel Company at Stoke-on-Trent, and the 50 years' experience of sinter plant construction behind the design has ensured that the plant is the best possible as far as the particular needs of this well-known steel company are concerned.

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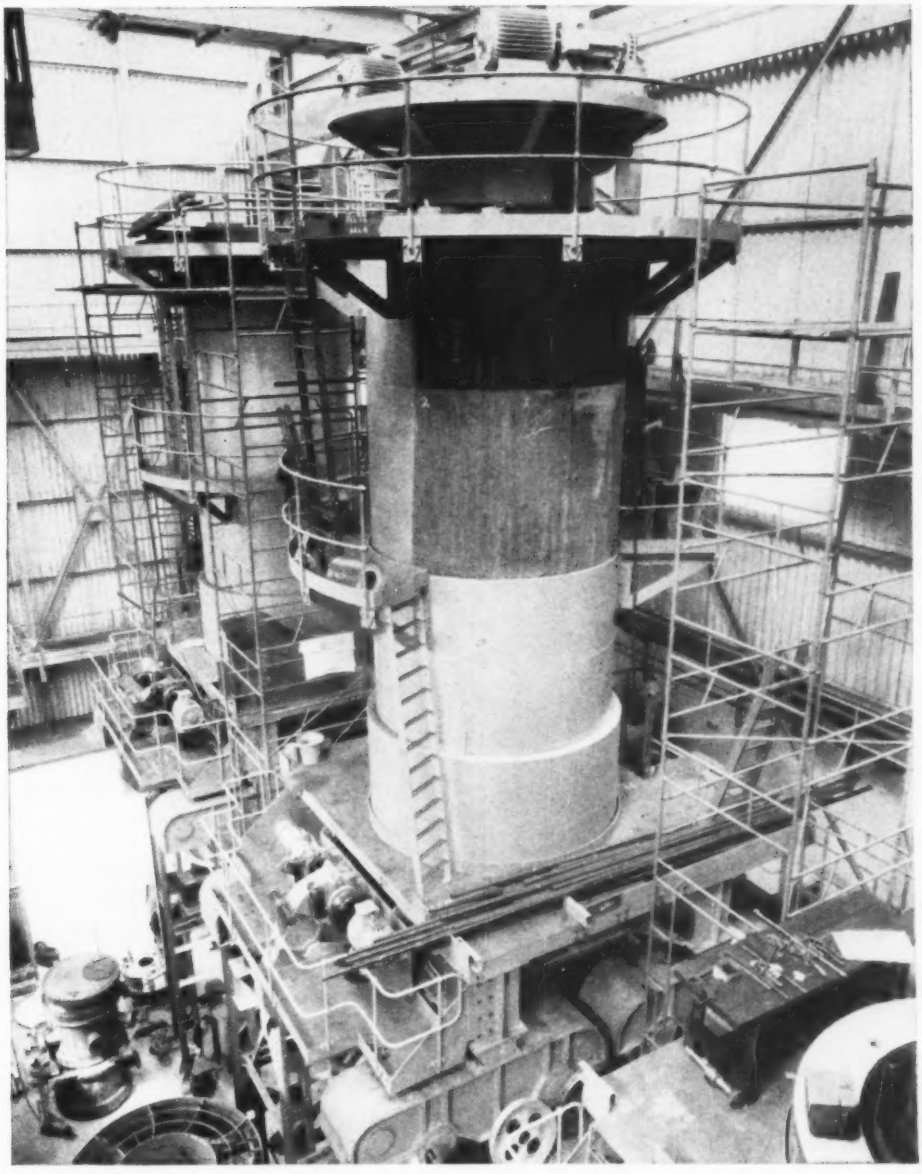
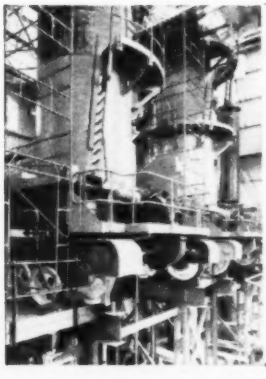
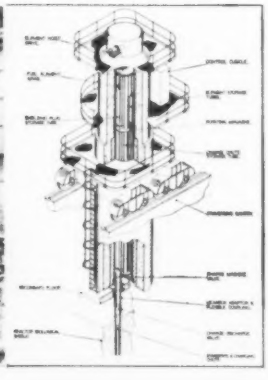


NUCLEAR REACTOR CHARGE-DISCHARGE EQUIPMENT FOR BRADWELL





Four 400 ton Reactor Charging Machines are now being assembled in a special 80 feet high erection bay at Bristol.

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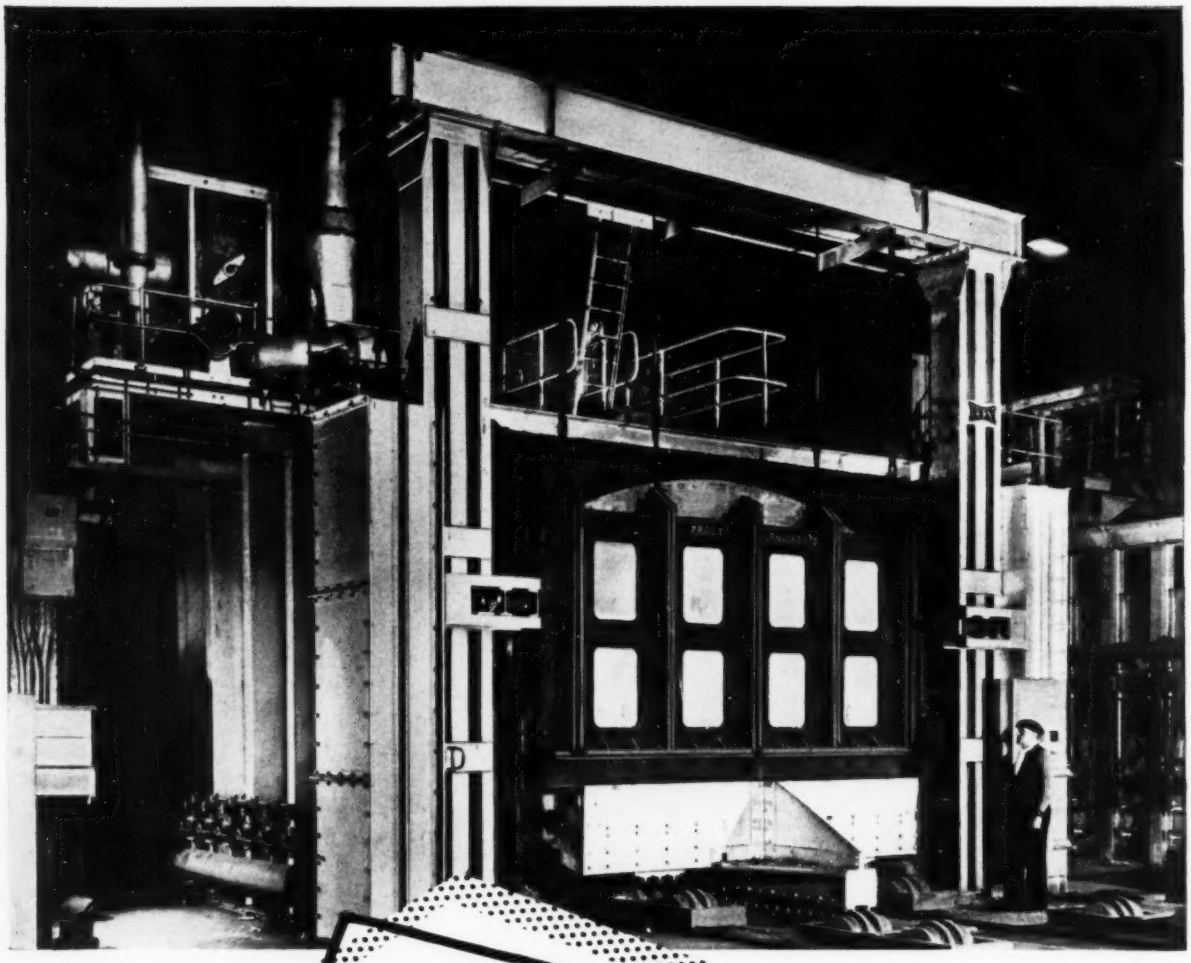

BOGIE TYPE REHEATING FURNACE FOR LARGE INGOTS FOR PLATE ROLLING

The above is one of a pair of Furnaces installed at the River Don Works of The English Steel Corporation Limited, Sheffield, for re-heating a standard load of six 13 ton stainless steel ingots to rolling temperature. Reversing type with multi-pass regenerators built above floor level and all auxiliary equipment located behind the Furnaces

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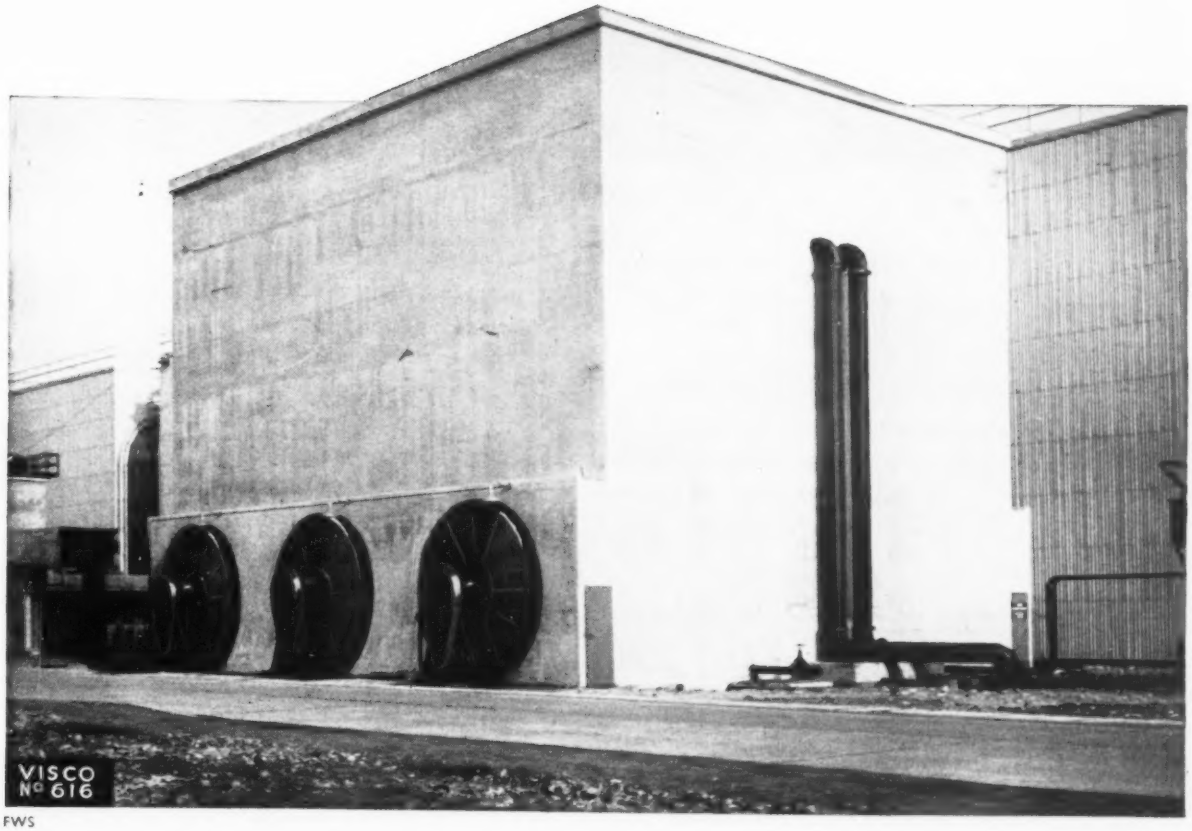
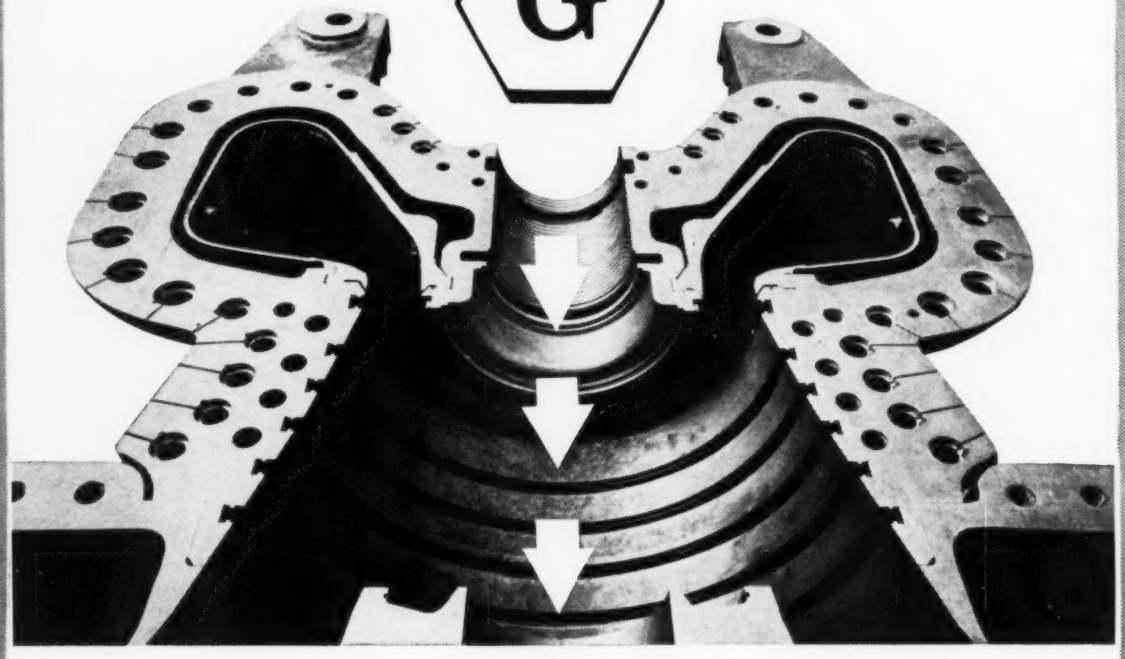
VISCO
Water Cooling.



FWS

R W G



This is the lower half of a gas turbine cylinder for a 2,500 kW gas turbo-alternator now running in a Midland steel works, converting the heat in waste blast-furnace gas into useful work. The provision of economical power is our business; and since we manufacture most of the main equipment for a power station such as boilers, turbines, alternators, condensers, feed heaters, cooling-water strainers, we are well equipped to design and carry through schemes for the efficient utilisation of any fuel.

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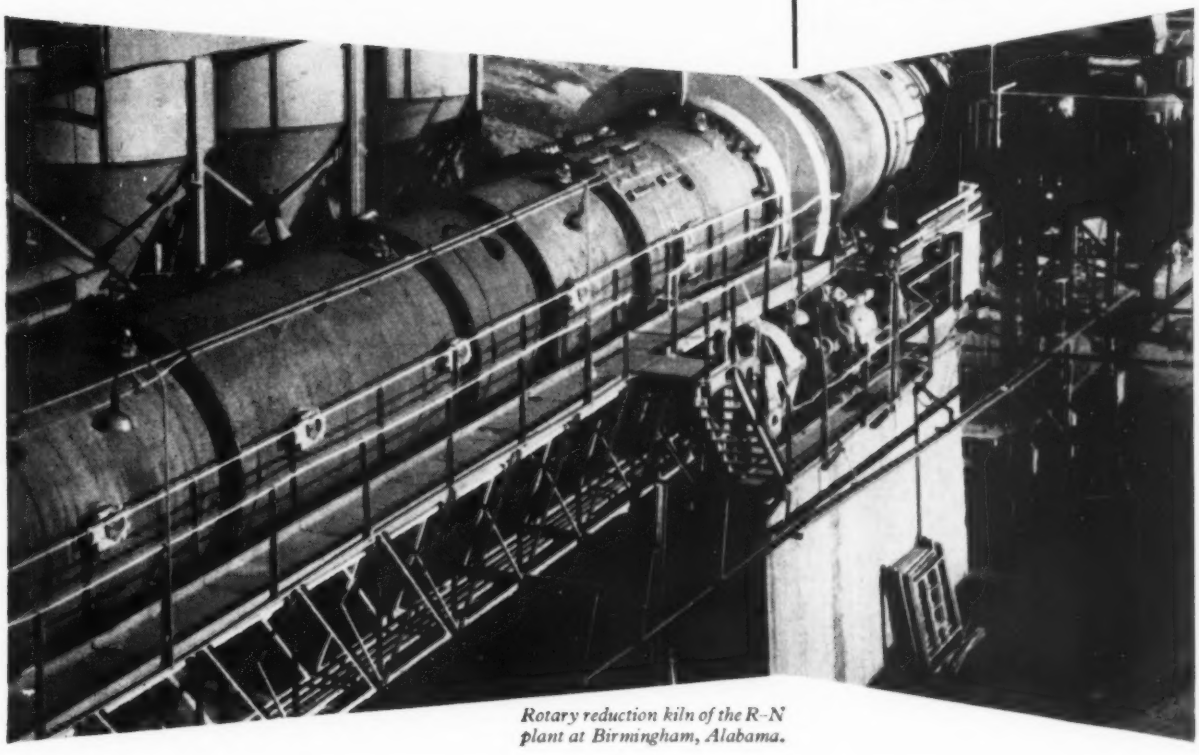
THE R-N PROCESS

for direct reduction of iron ore and subsequent wet separation of gangue



Rotary reduction kiln of the R-N plant at Birmingham, Alabama.

R-N Product replaces pig iron as well as scrap

The R-N Process provides the world's steel industry with a new steel furnace feed material from ores of nearly all types by direct reduction utilizing various types of solid, low-cost fuel and surplus gas if available.

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The sulphur content of the concentrate is below 0.05%.

The concentrate is dried and formed into briquettes.

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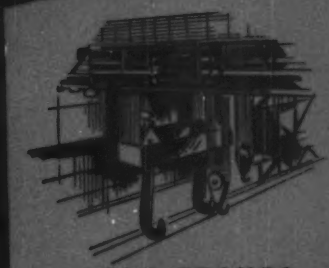
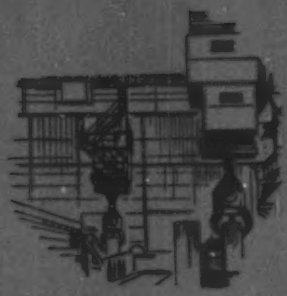
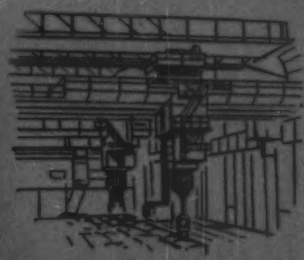
STEELWORKS EQUIPMENT *by* ADAMSON-ALLIANCE



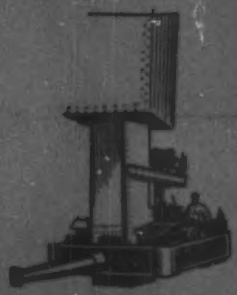
LADLE CRANES



SOAKING PIT CRANES



STRIPPING CRANES



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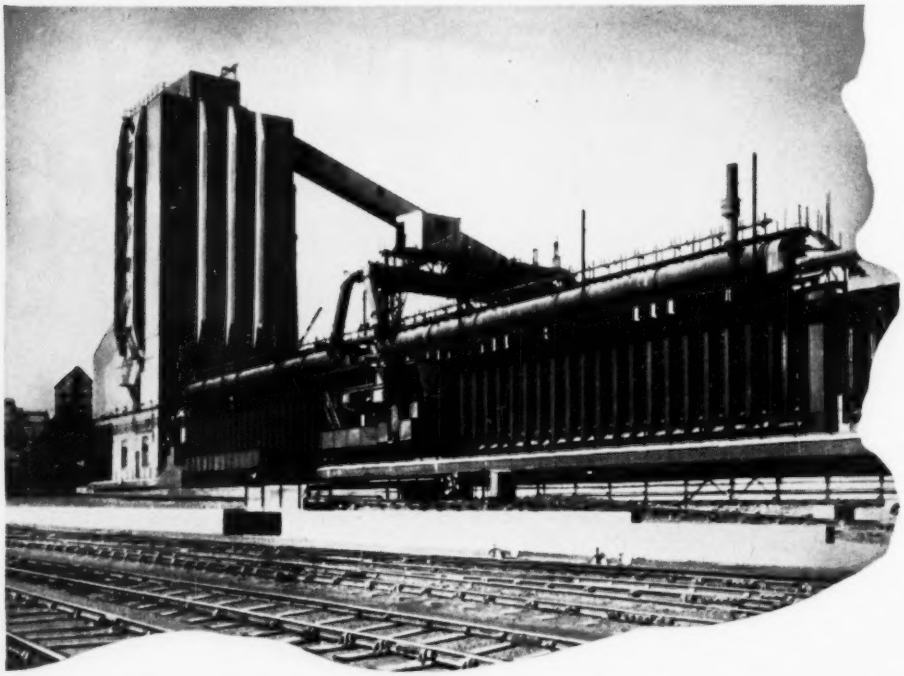

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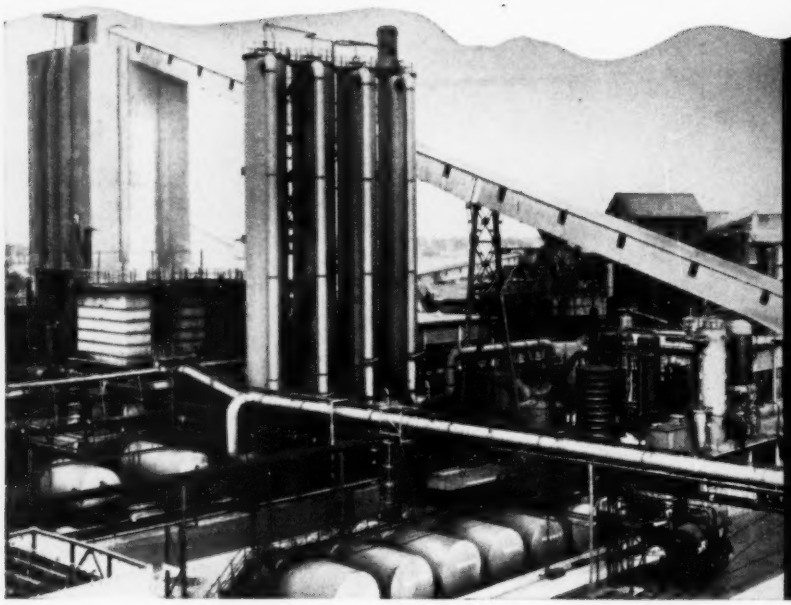

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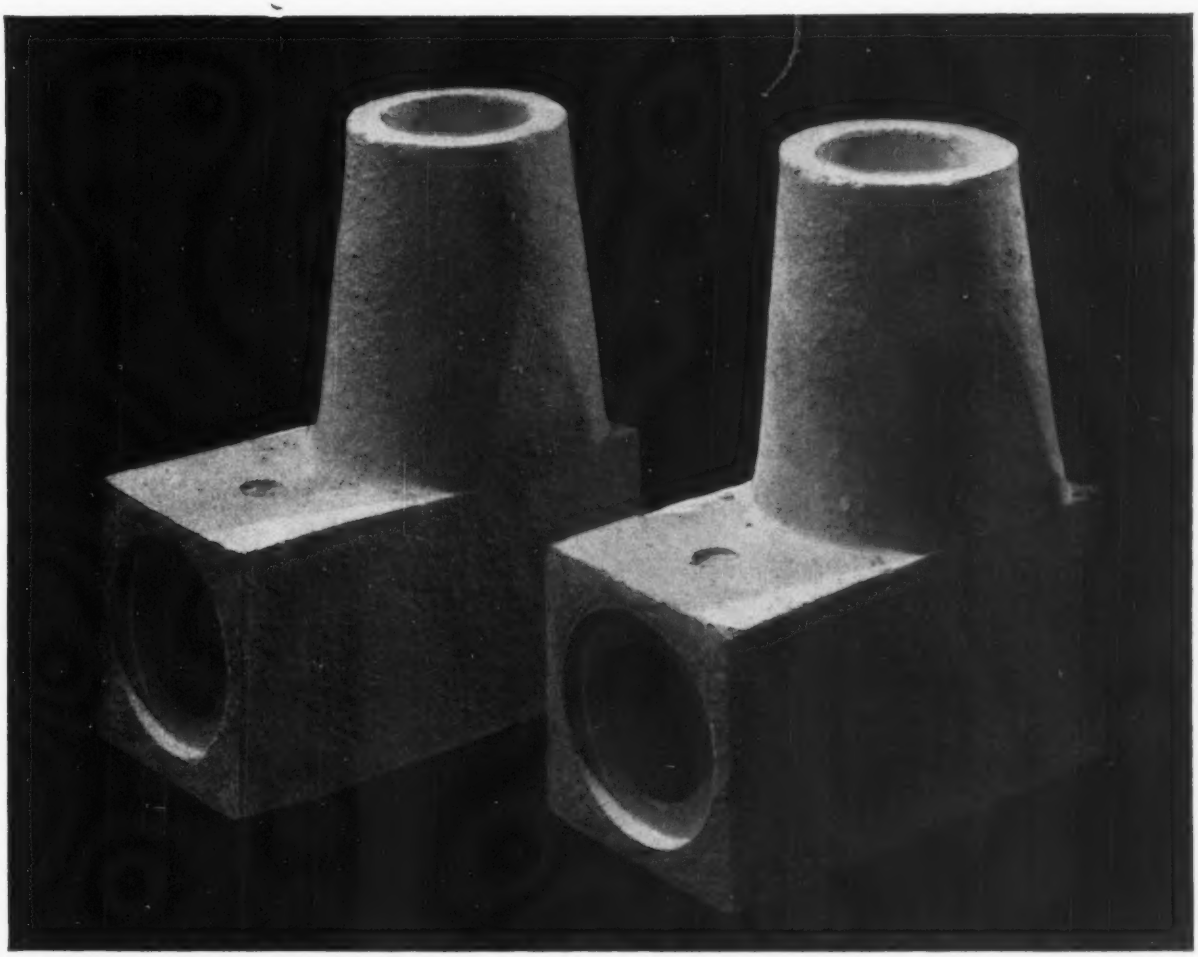
NEWCASTLE-ON-TYNE: MANSION HOUSE CHAMBERS, THE CLOSE



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Wraggs of Sheffield take justifiable pride in their end runner bricks as finished products. But they never forget that casting pit refractories are means to another end—that of producing clean, reliable steel for the world's great industries. That's why no refractories are allowed to leave Wraggs' works unless they are up to the highest standards of manufacture.

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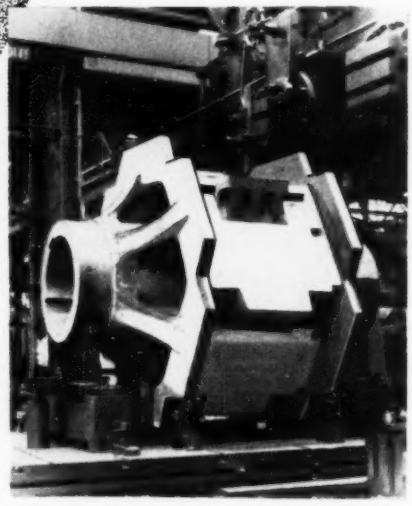
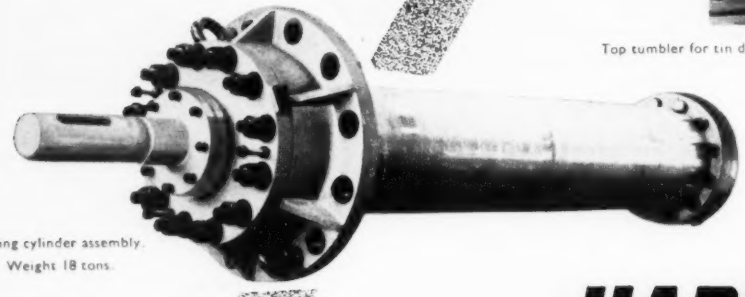


Top tumbler for tin dredging. Weight 17½ tons.



Tilting cylinder assembly. Weight 18 tons.

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'Specialist-designed' Refractories

MULLOX Brand

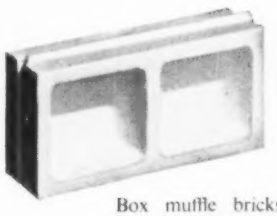
SILLIMANITE BRICKS AND SHAPES

' Mullox ' bricks have been specially designed for all structures subjected to mechanical stress or thermal shock at high temperatures. By suitable kiln-firing treatment they acquire excellent spalling resistance and at extreme temperatures exhibit negligible volume changes.

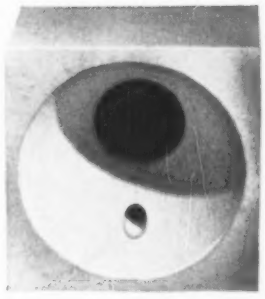
All brands are characterised by a low amount of fluxing impurities, which is ensured by using Sillimanite bonded with varying amounts of pure Devon Ball Clay.

They withstand the corrosive action of most slags and are not attacked by either oxidising or reducing atmospheres.

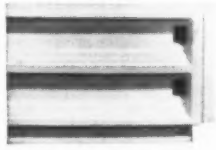
All jointing should be carried out with ' Mullox ' cement which has been developed specially for use with ' Mullox ' bricks.



Box muffle bricks for heat-treatment furnaces



Burner block



Electrical resistor tile

Radiant heater block

APPLICATIONS

Combustion Chambers and fireboxes
Burner Blocks
Gas Port Blocks
Burner Baffles
Hearth Tiles
Sidewalls
Roofs
Hot repair Tiles

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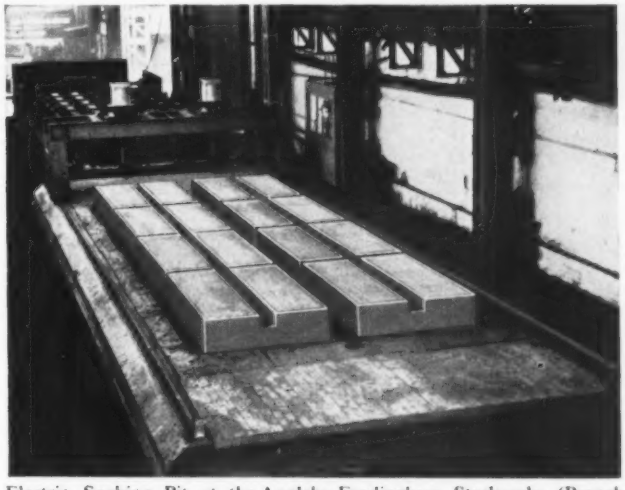
SEMI-SILICA BRICKS SHAPES AND CEMENTS

The Swann Brassington semi-silica brick is prepared by blending specially hand picked sand from the Company's extensive deposits with a small amount of Devon Ball Clay, thereby ensuring a consistent product with a minimum amount of adventitious impurity.

Semi-silica bricks are characterised by a considerably higher resistance to thermal shock than normal silica bricks, volume stability, and a tendency to glaze in service. When used in conjunction with Swann Brassington siliceous cement, the bricks and cement glaze together forming a monolithic structure. Failure due to joint erosion is therefore eliminated. The bricks have a high resistance to erosion by slag attack and to abrasion by dust-laden furnace gases.



Electric Soaking Pit at the Appleby-Frodingham Steelworks (Branch of the United Steel Company Ltd.). With acknowledgements to Stein & Atkinson Ltd.

APPLICATIONS

Reheating Furnaces, Complete Linings
Soaking Pits, Complete Linings
Construction of Slag Pocket Arches
Construction of Stoker Arches
Side Walls of Combustion Chambers, Complete
Furnace Door Linings
Complete Open Hearth Furnace
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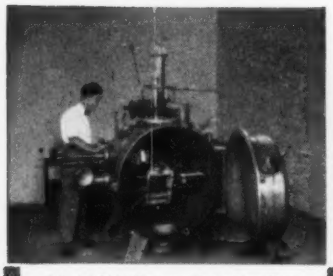
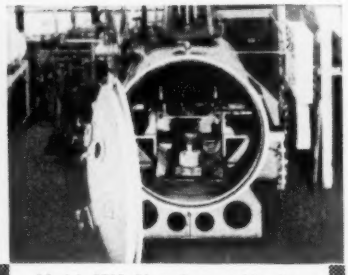
Write for details of the Wild-Barfield—NRC range of high vacuum plant.



Model 2555 Vacuum Induction Furnace with melting capacity of 50 pounds of steel. Other standard furnaces have capacities of 12 to 3,000 pounds.



Model 2705 Non-Consumable Arc Skull Furnace with a capacity of 50 pounds of titanium. Other standard vacuum arc furnaces have capacities of 8 to 10,000 pounds of titanium.

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for **all** *heat-treatment purposes*

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No. 17	Dry	+1750°C	Hydraulic	1200°C	1700°C	160
No. 18	Dry	+1750°C	Hydraulic	1200°C	1800°C	160
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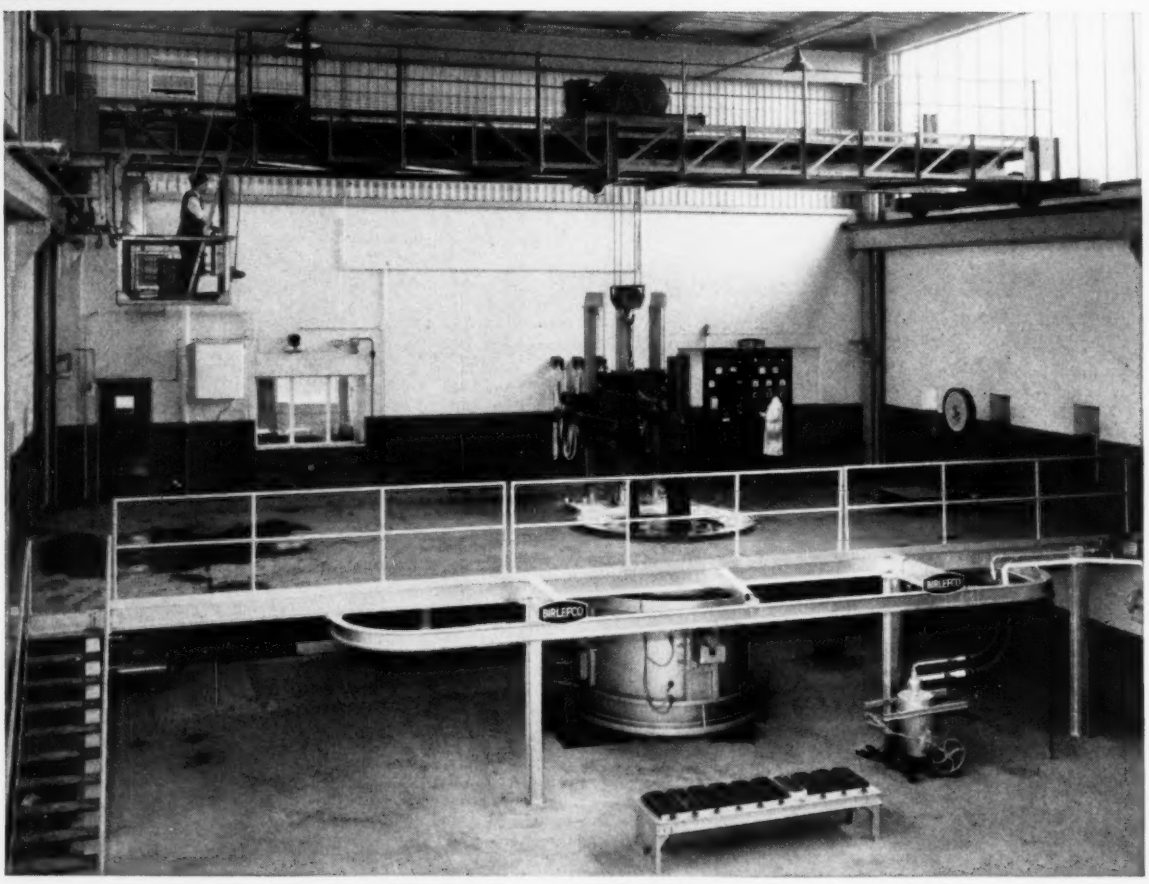
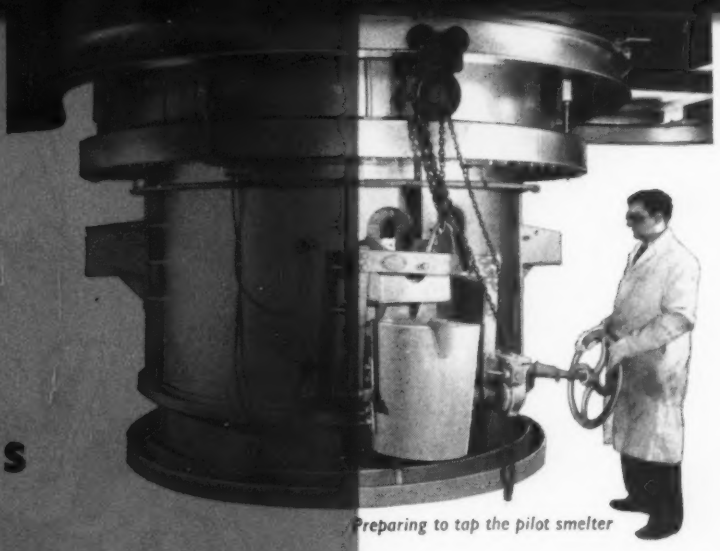
ELECTRIC SMELTING ON APPROVAL

for the first time in this country a



The Birlefco pilot smelting plant at Aldridge

TRIAL TESTS ON RAW MATERIALS



Preparing to tap the pilot smelter

contract service for electric smelting

For the first time in this country a contract service is available for electric smelting. A pilot smelting furnace, built by Birlec-Efco (Melting) Limited, is in operation at the Company's Aldridge premises to promote the development of electric smelting processes. The furnace, which is available to companies throughout the world, provides full scale testing facilities for the mining and electro-chemical industries.

Raw materials are accepted in trial batches for testing their amenity to electro-thermal reduction and for determining the most suitable smelting technique and the nature of the resultant products. At a fee agreed in advance the pilot smelting furnace is operated on customers' raw materials. Finished products and the balance of materials are returned to customer. At the end of the test Birlefco presents a full report giving recommendations on smelting practice, electrical ratings and size of installation required for a given output.

ELECTRIC SMELTING OF

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IRON ORES
MANGANESE ORES
FERRO CHROME
FERRO-SILICON
NICKEL AND COPPER CONCENTRATES

Treatment of Slags and other electro-thermal processes

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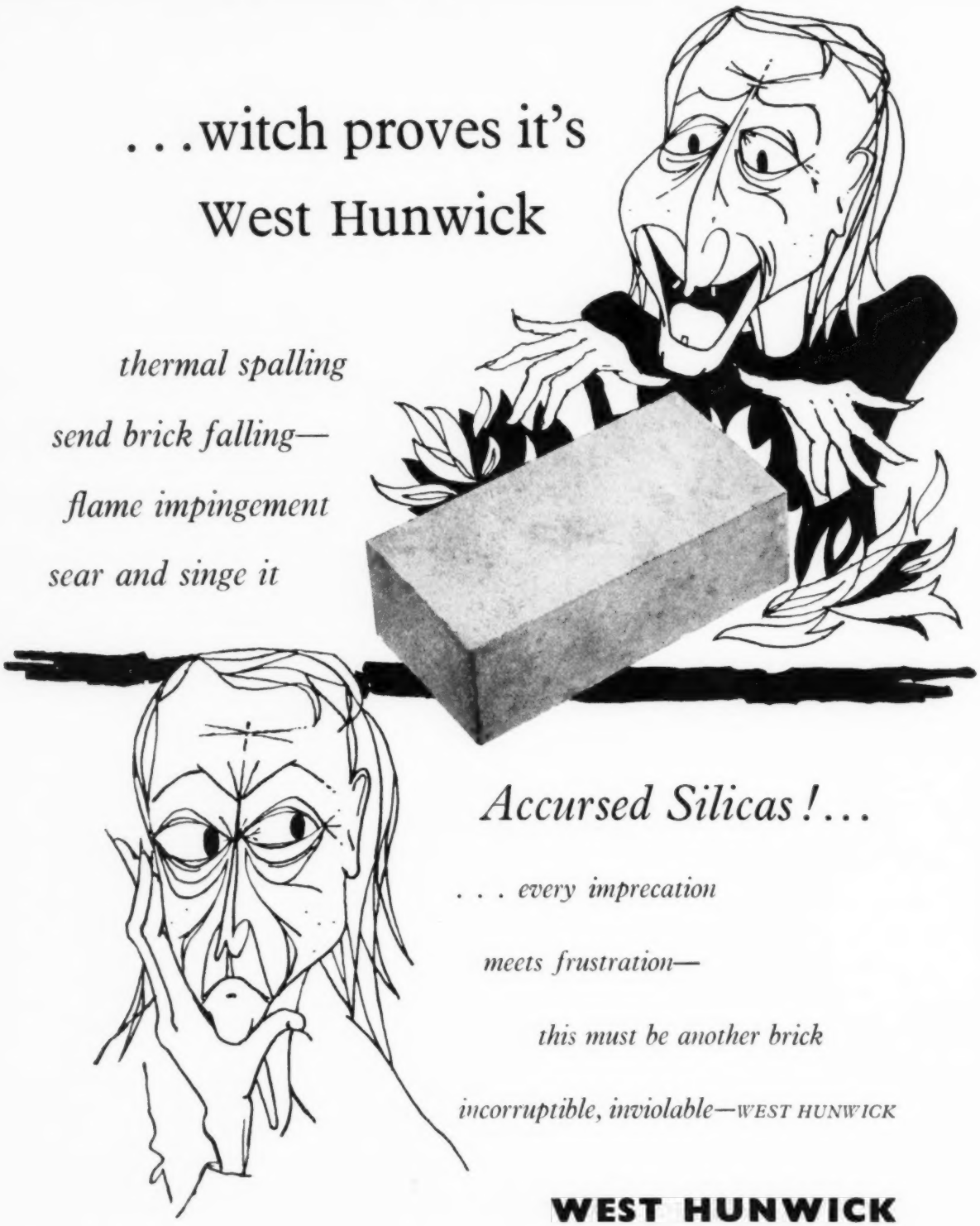
. . . witch proves it's West Hunwick



thermal spalling

send brick falling—

flame impingement

sear and singe it

Accursed Silicas!...

. . . every imprecation

meets frustration—

this must be another brick

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HUNNEX Brand—high duty quality
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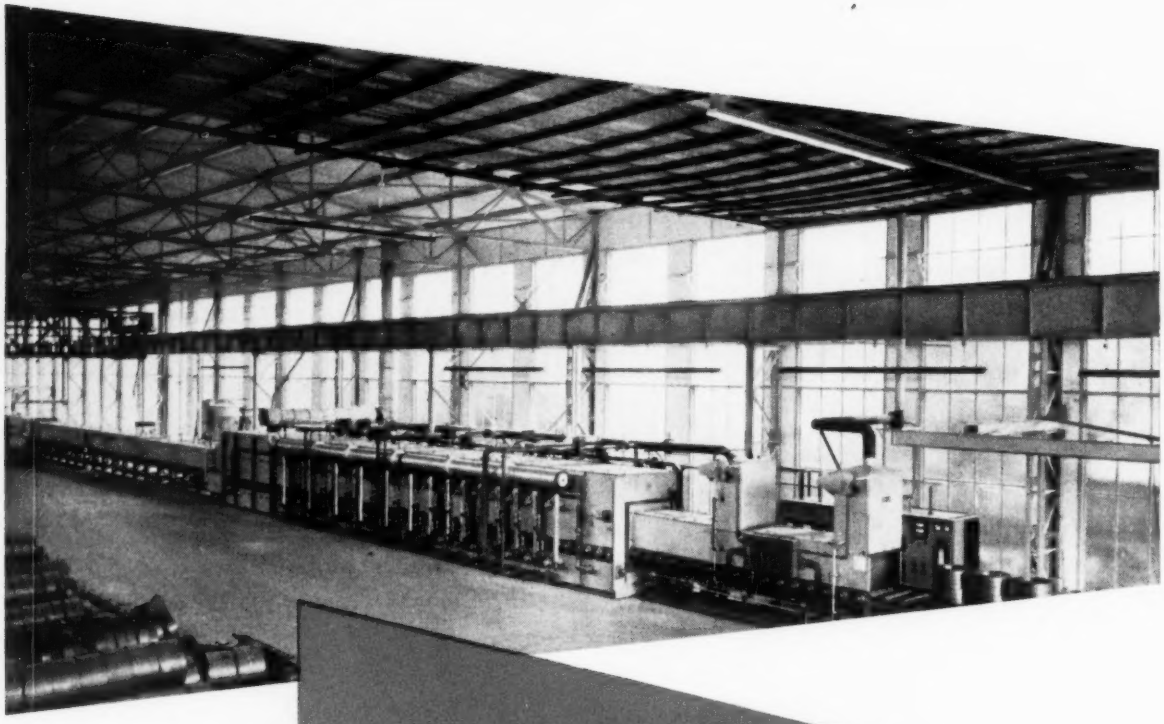

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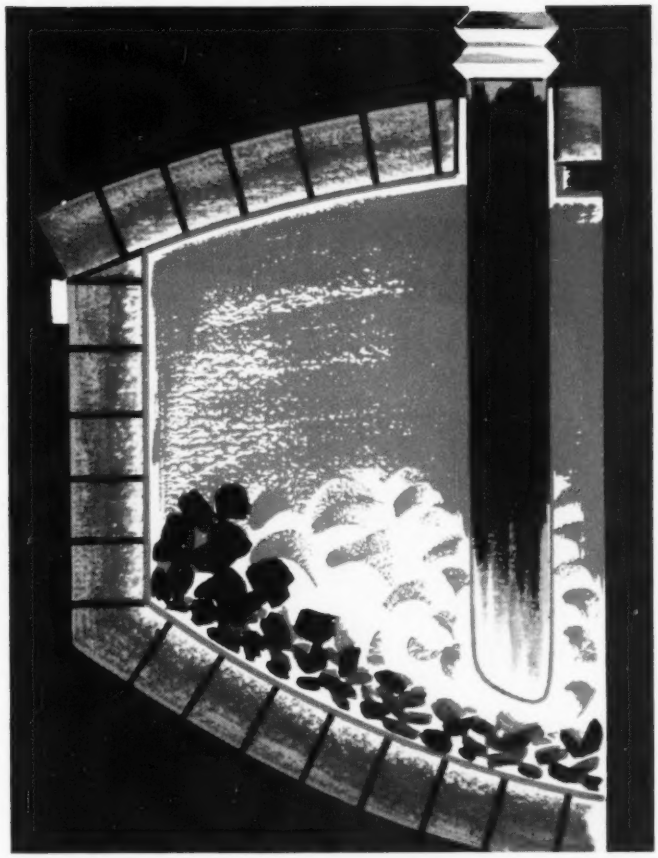

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HIGH MECHANICAL STRENGTH AT OPERATING TEMPERATURES

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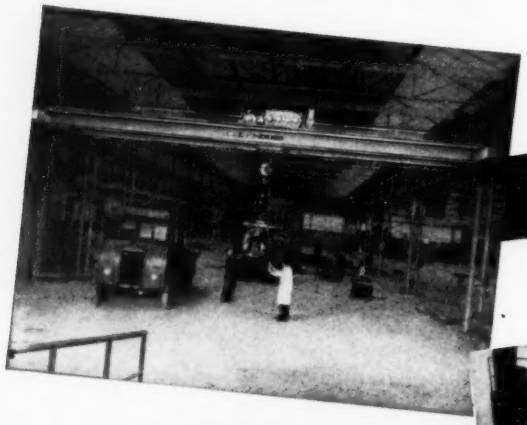
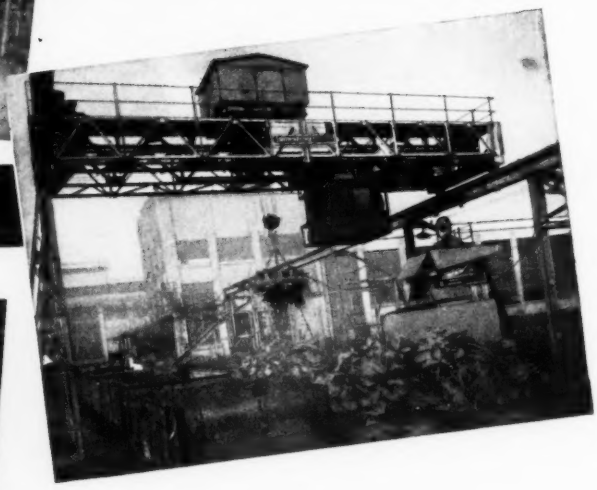
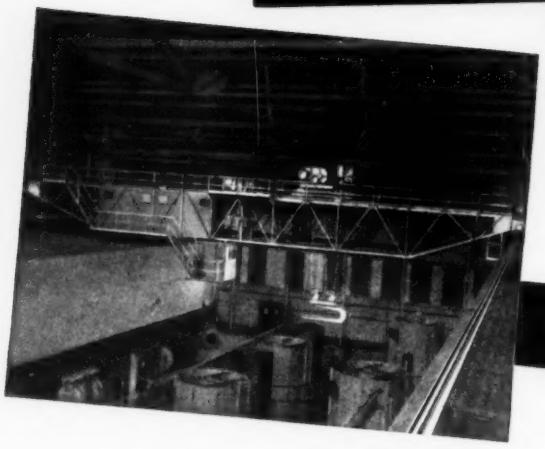


Floor Operated



Outdoor



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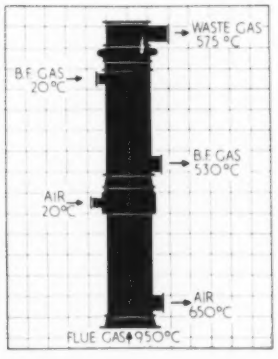

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This design of Air and Gas Recuperator is fitted to eight one-way fired soaking pits at the Appleby-Frodingham Steel Co., Scunthorpe, each equipped with a Flue Tube Air Recuperator and Blast Furnace Gas Recuperator in "tower" formation, the gas recuperator being vertically above the air recuperator in each case. The latest four sets are designed for heating 170,000 c.f.h. of combustion air to 650°C, and 230,000 c.h.f. of blast furnace to 530°C.

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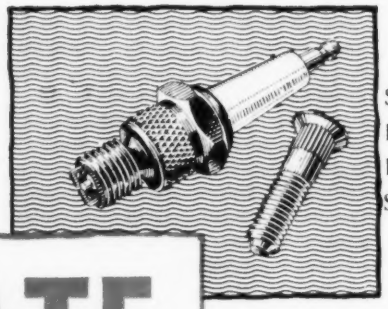

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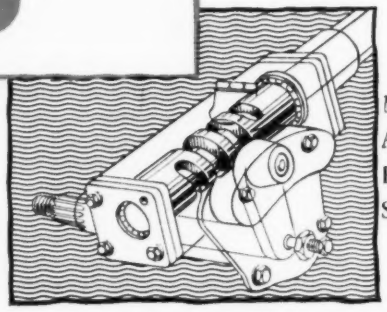

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For machining, bright drawing, forging, drop stamping and general engineering.

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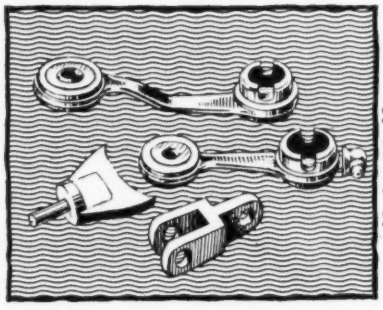

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Coils may be split if required.

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0.240″ to 0.550″ in 500 lb. coils.
0.550″ to 1.000″ in 900 lb. coils.
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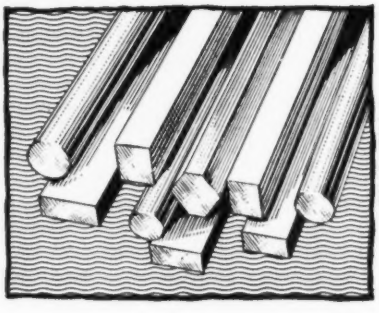

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Circular, specially reamed ends ensure gas tight closures with rubber bungs. Porous Alumina plugs to prevent iron oxide carry-over also available.

For use in any high temperature furnace, particularly for carbon and sulphur determination in steel, operating at temperatures up to 1500°C (2732°F). These tubes are completely reliable, do not devitrify or allow loss of combustion gases even up to maximum working temperatures. Thermal aluminous porcelain 525 sheaths are excellent for use as pyrometer sheaths up to 1500°C.

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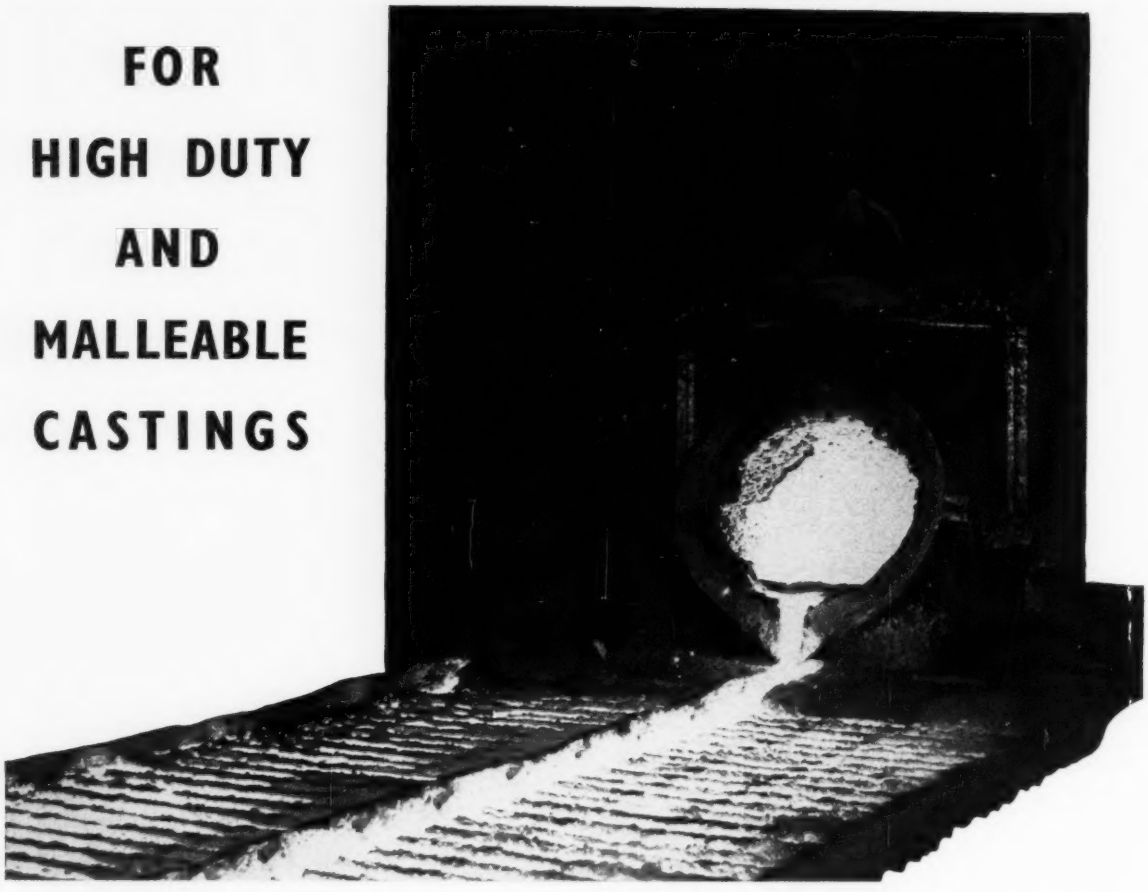


The seven standard grades of Stanton Dale Refined Pig Iron

GRADES:	A	B	C	D	E	F	G
SILICON%	1·9–2·1	1·4–1·6	0·9–1·1	2·25–2·5	0·9–1·1	1·4–1·6	1·9–2·1
SULPHUR%	0·06	0·07	0·08	0·05	0·08	0·07	0·06
PHOSPHORUS%	0·6–0·7	0·6–0·7	0·6–0·7	0·4–0·5	0·25	0·25	0·25
MANGANESE%	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5
TOTAL CARBON%	2·7–3·0				2·8–3·1		

In addition to the above other grades of Dale Refined Iron can be supplied to meet more exacting demands which call for alloy additions and special processing.

STANTON *Dale Refined* PIG IRON

THE STANTON IRONWORKS COMPANY LIMITED NEAR NOTTINGHAM

For the visual examination of "open-hearth" furnaces . . .

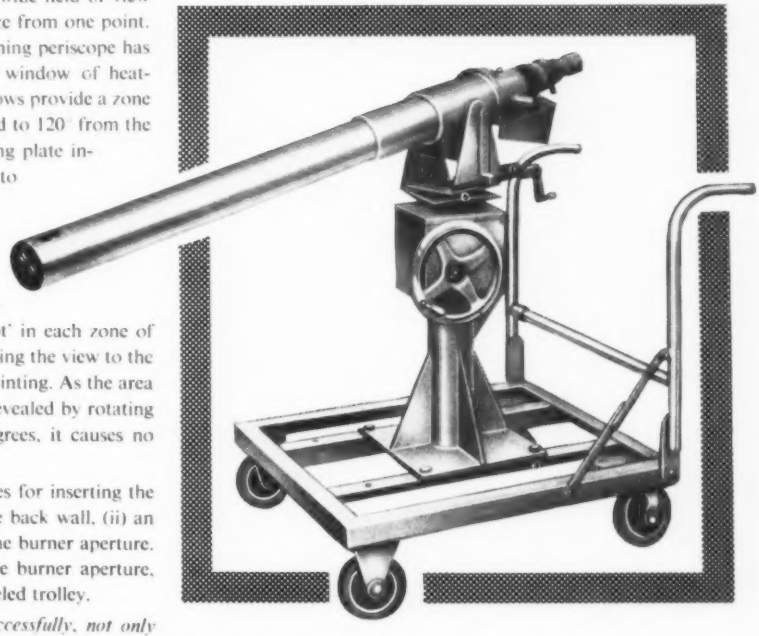
FOSTER-BISRA FURNACE SCANNING PERISCOPE

Patent No. 796406

is the answer

Studying the furnace flame, investigating temperature distribution and observing the erosion of refractories are among the many uses of the furnace scanning periscope developed by BISRA's Physics Department for viewing the interiors of open-hearth furnaces. The problem which had to be solved was a formidable one : to devise an instrument capable of giving a view of the whole interior of the furnace and of withstanding the intense heat, and yet slender enough to be inserted through a small opening in the furnace wall.

The need to protect the optical system from heat makes it difficult to obtain the very wide field of view required to see all parts of the furnace from one point. The water-jacket of the furnace scanning periscope has three apertures, each covered by a window of heat-absorbing glass. Together these windows provide a zone of view extending from straight-ahead to 120° from the axis of the periscope. A half-reflecting plate inside the instrument can be rotated to receive light from any of the three windows, thus covering the 120° field in three sections. By rotating the periscope on its own axis, the entire interior of the furnace can be scanned. There is a small 'blind spot' in each zone of view ; this is the price paid for extending the view to the direction in which the periscope is pointing. As the area obscured by this blind spot can be revealed by rotating the periscope on its axis a few degrees, it causes no inconvenience.



Three of the most suitable places for inserting the periscope into the furnace are (i) the back wall, (ii) an aperture in the charging door, (iii) the burner aperture. Except when it is being used at the burner aperture, the instrument is mounted on a wheeled trolley.

The periscope has been used successfully, not only for visual examination of furnaces, but for still and cine photography and closed-circuit television. Its optical performance is more than adequate for all these purposes.

For full details contact

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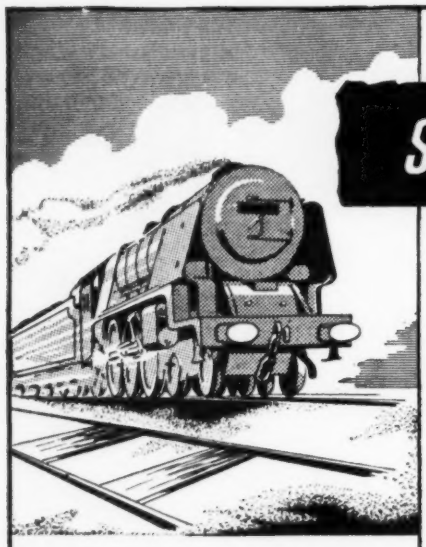

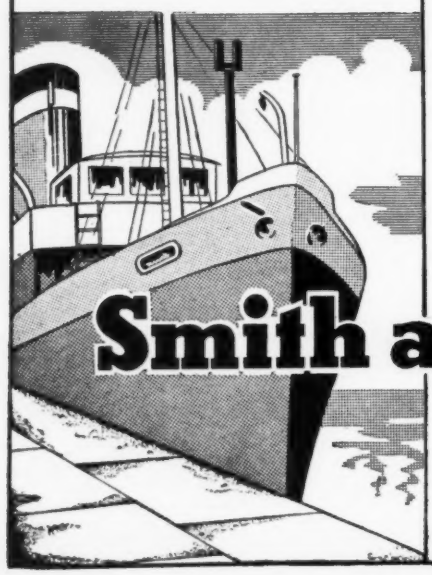

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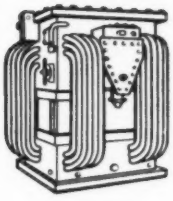
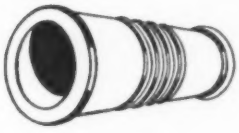


from transformers

to bellows 

the relief of stresses demands

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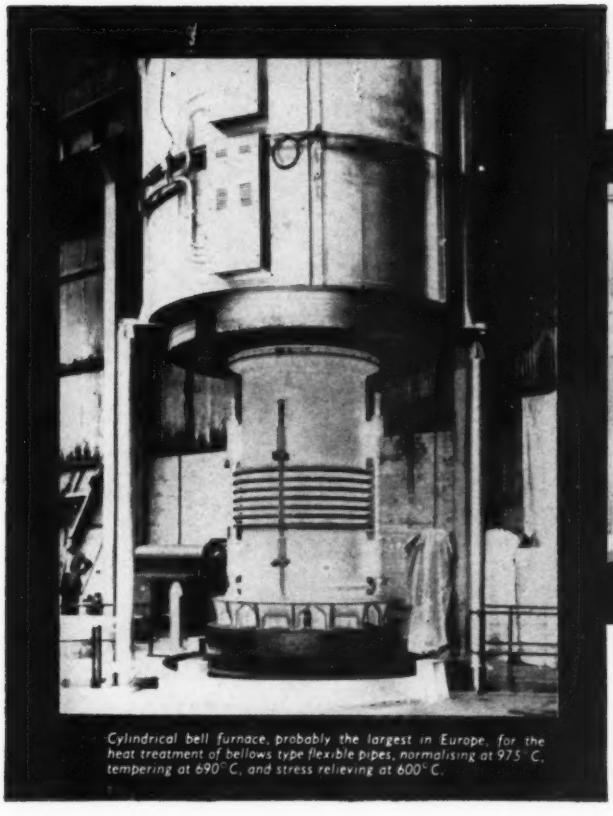
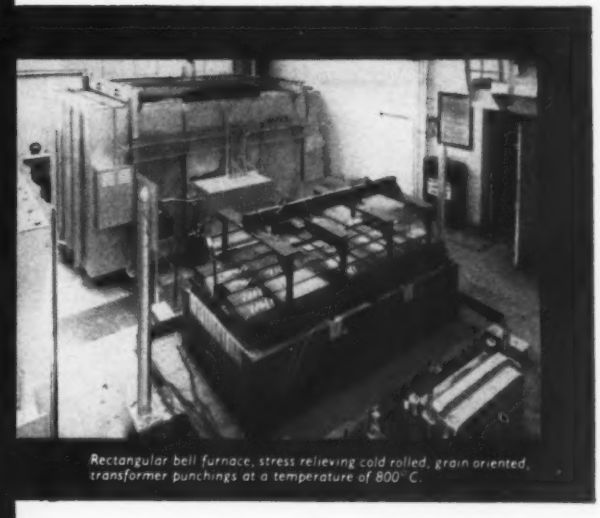
BELL TYPE FURNACES



Cylindrical bell furnace, probably the largest in Europe, for the heat treatment of bellows type flexible pipes, normalising at 975° C, tempering at 690° C, and stress relieving at 600° C.



Rectangular bell furnace, stress relieving cold rolled, grain oriented, transformer punchings at a temperature of 800° C.

When you need to heat treat ferrous or non-ferrous metals, in strip or wire or fabricated form, in rectangular or cylindrical furnaces, in controlled atmosphere or in vacuum — choose an Efco Bell.

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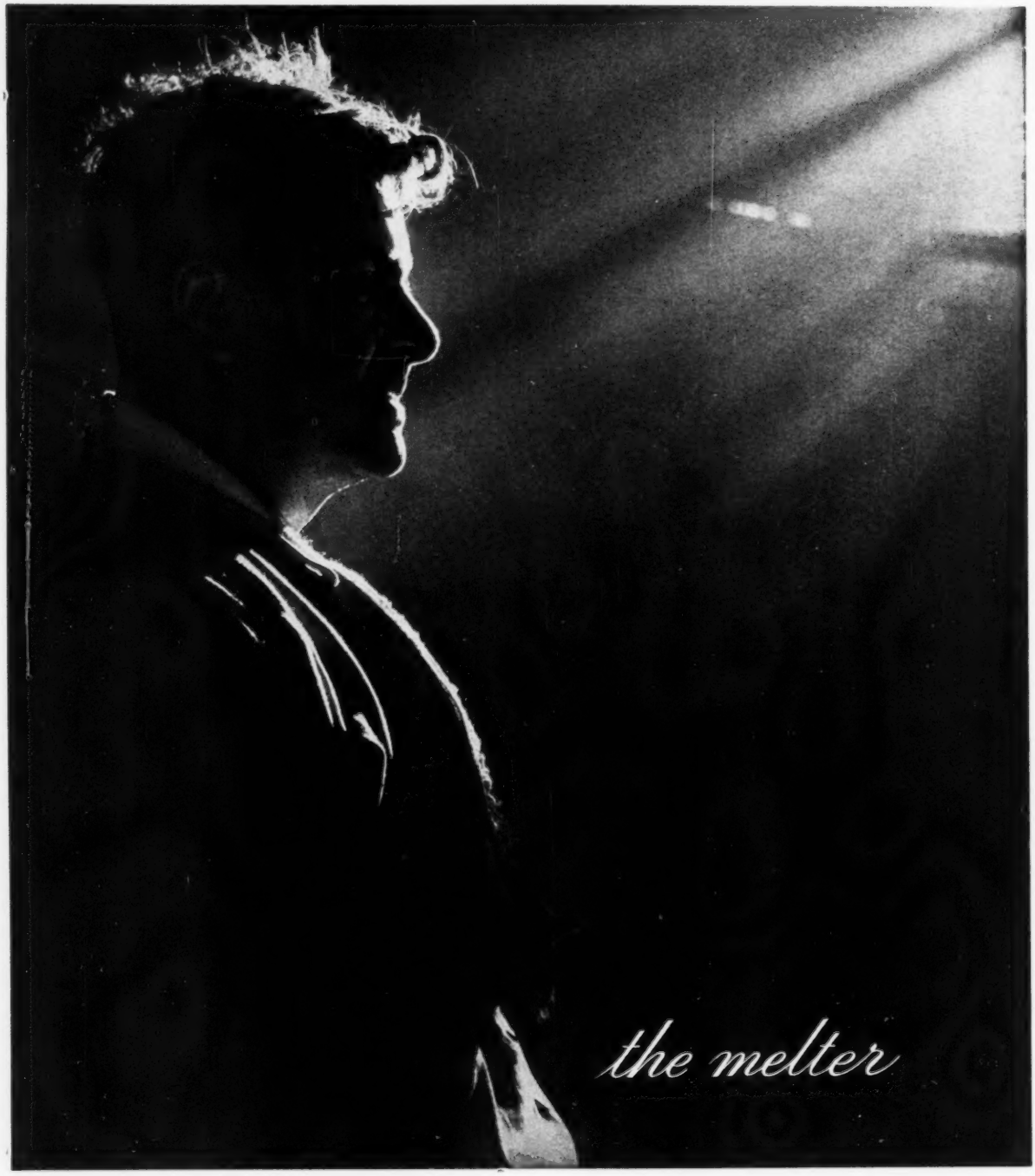

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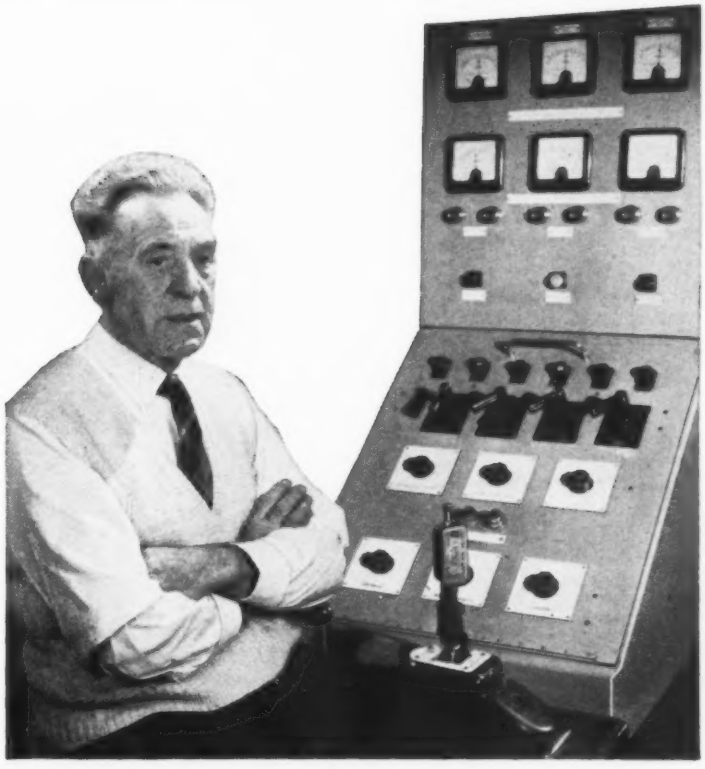
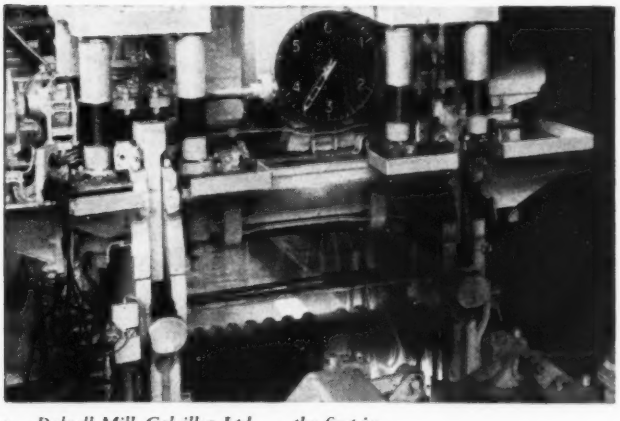
automatic control for hot reversing mills



'ENGLISH ELECTRIC' automatic programming equipment gives the operator the equivalent of another pair of hands.



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After preselection of the rolling programme, using either Punch Card or Uniselector systems, the operation of the screwdowns, manipulators and mill speed is fully automatic. It also has the following advantages:

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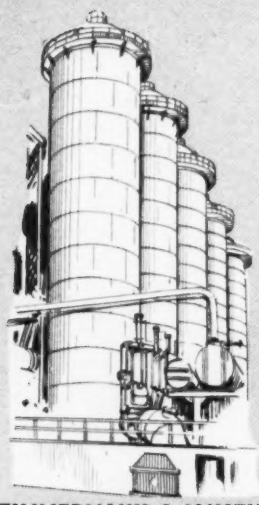

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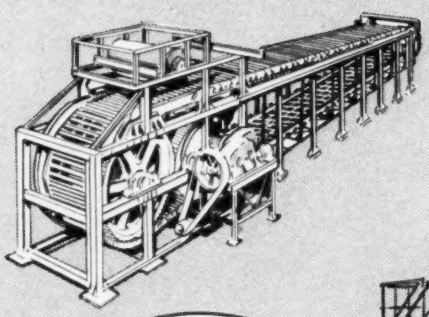

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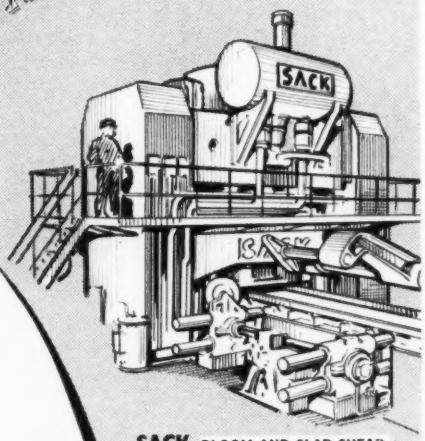

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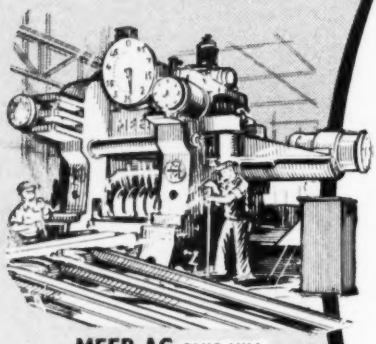
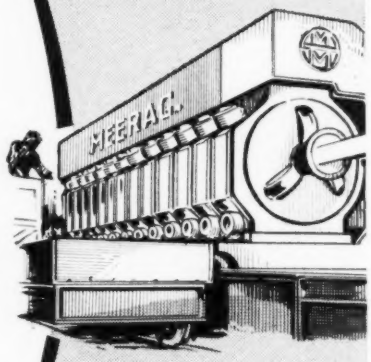
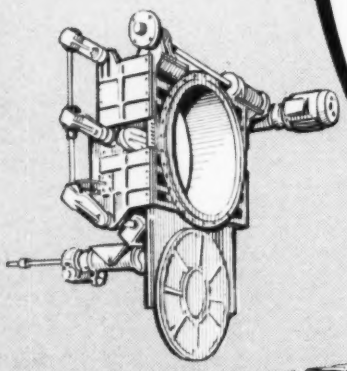


MEER AG PLUG MILL



MEER AG STRETCH REDUCING MILL



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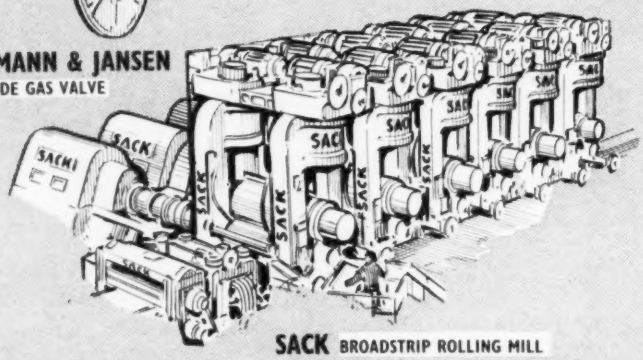
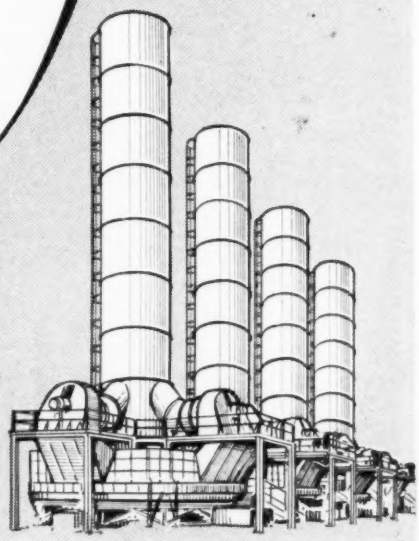
CRUDE GAS VALVE



SACK BROADSTRIP ROLLING MILL



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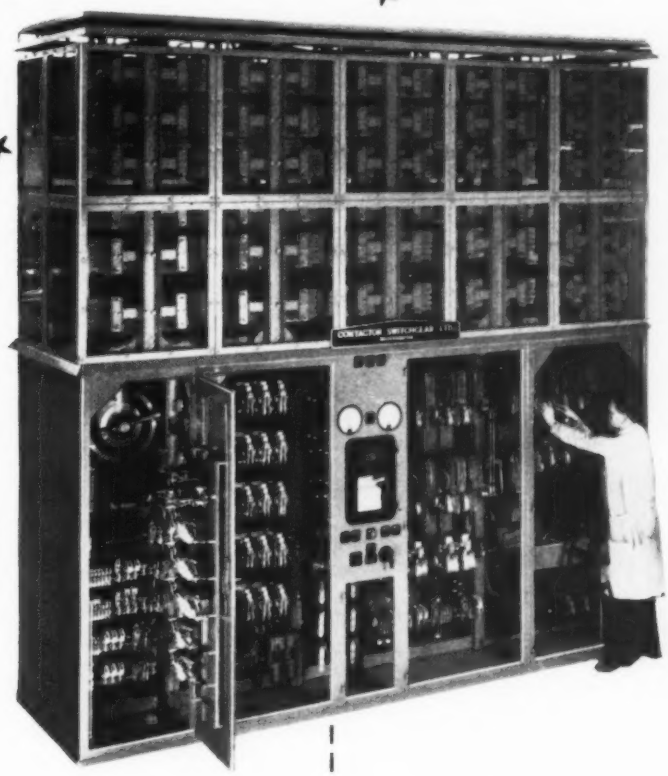

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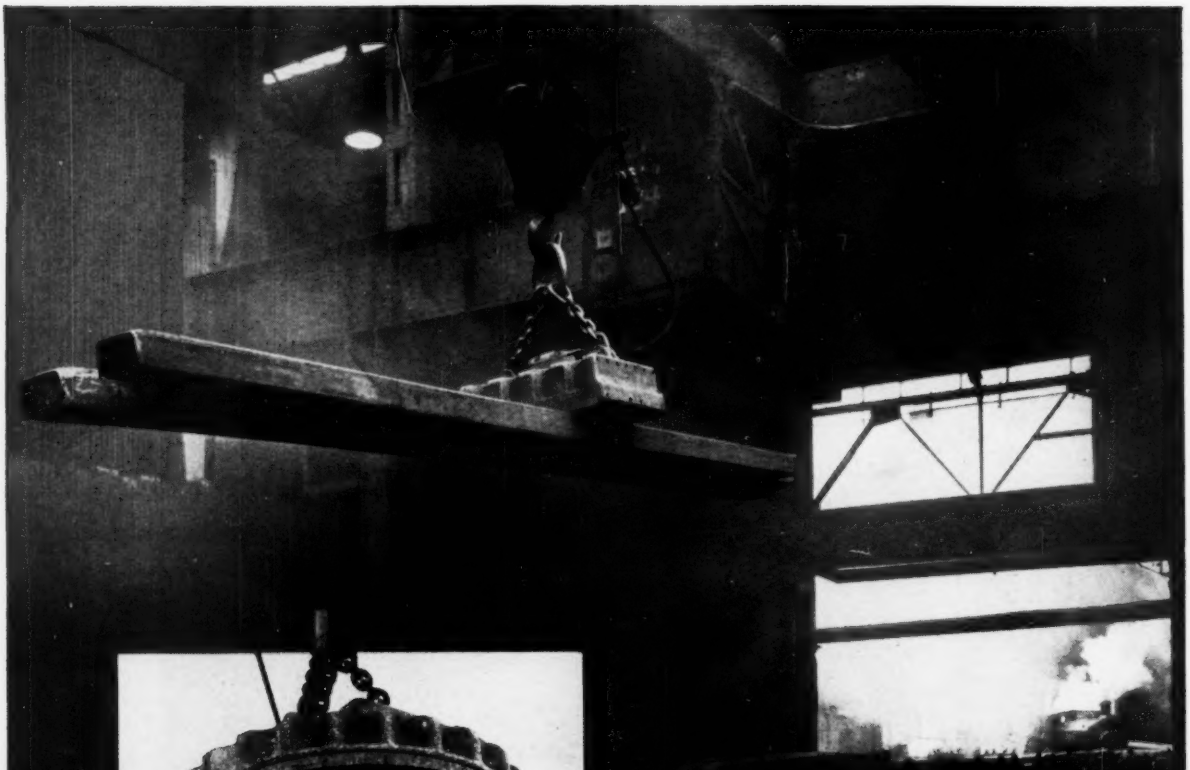

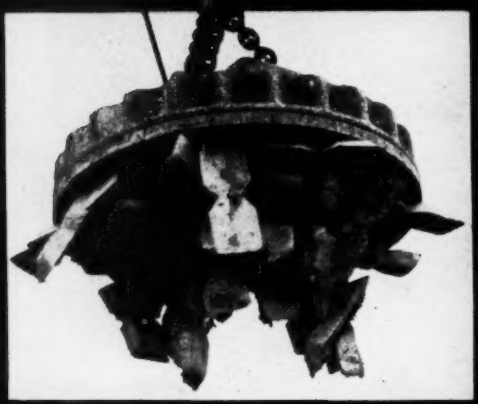

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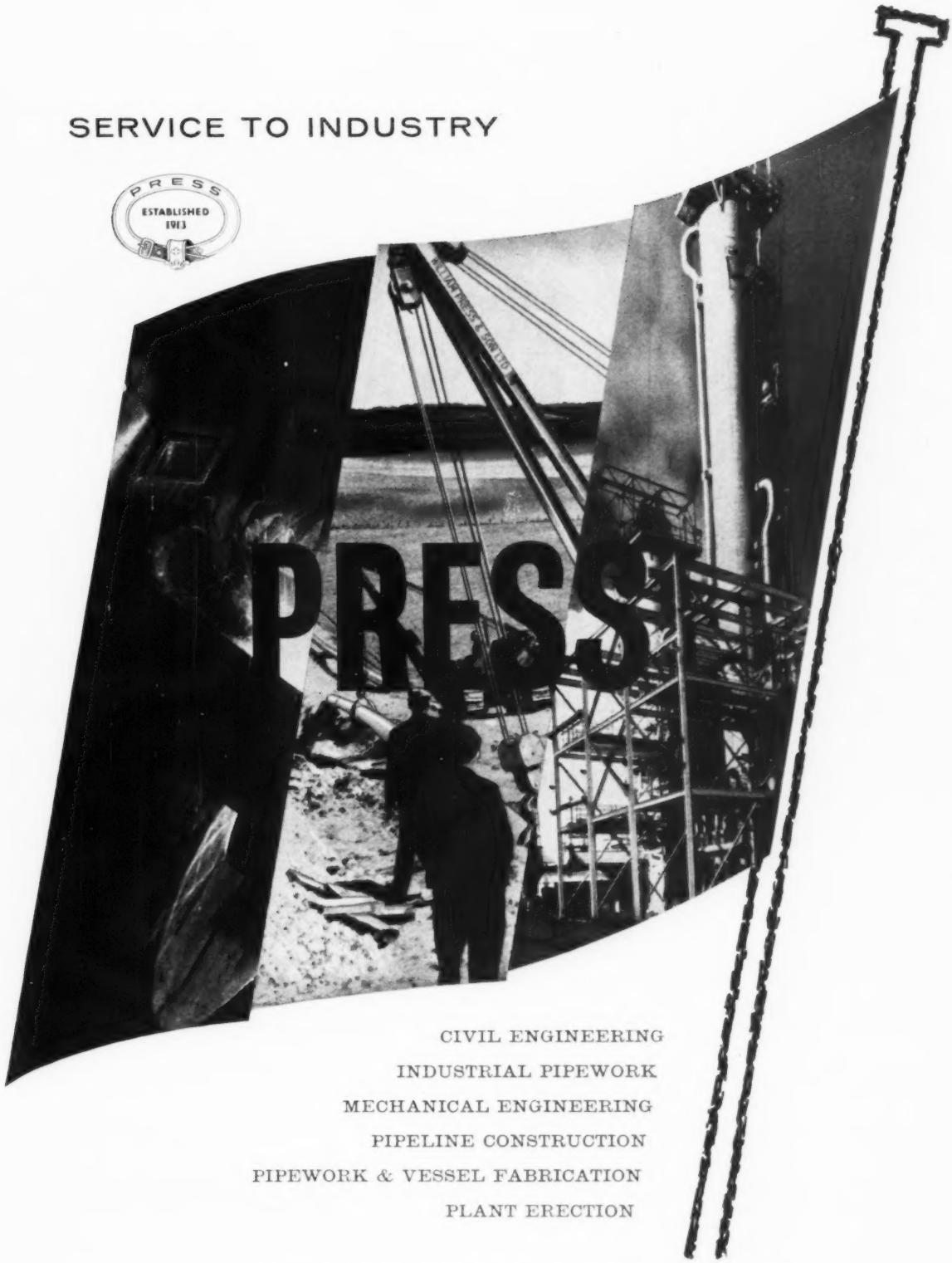

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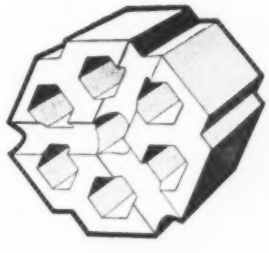

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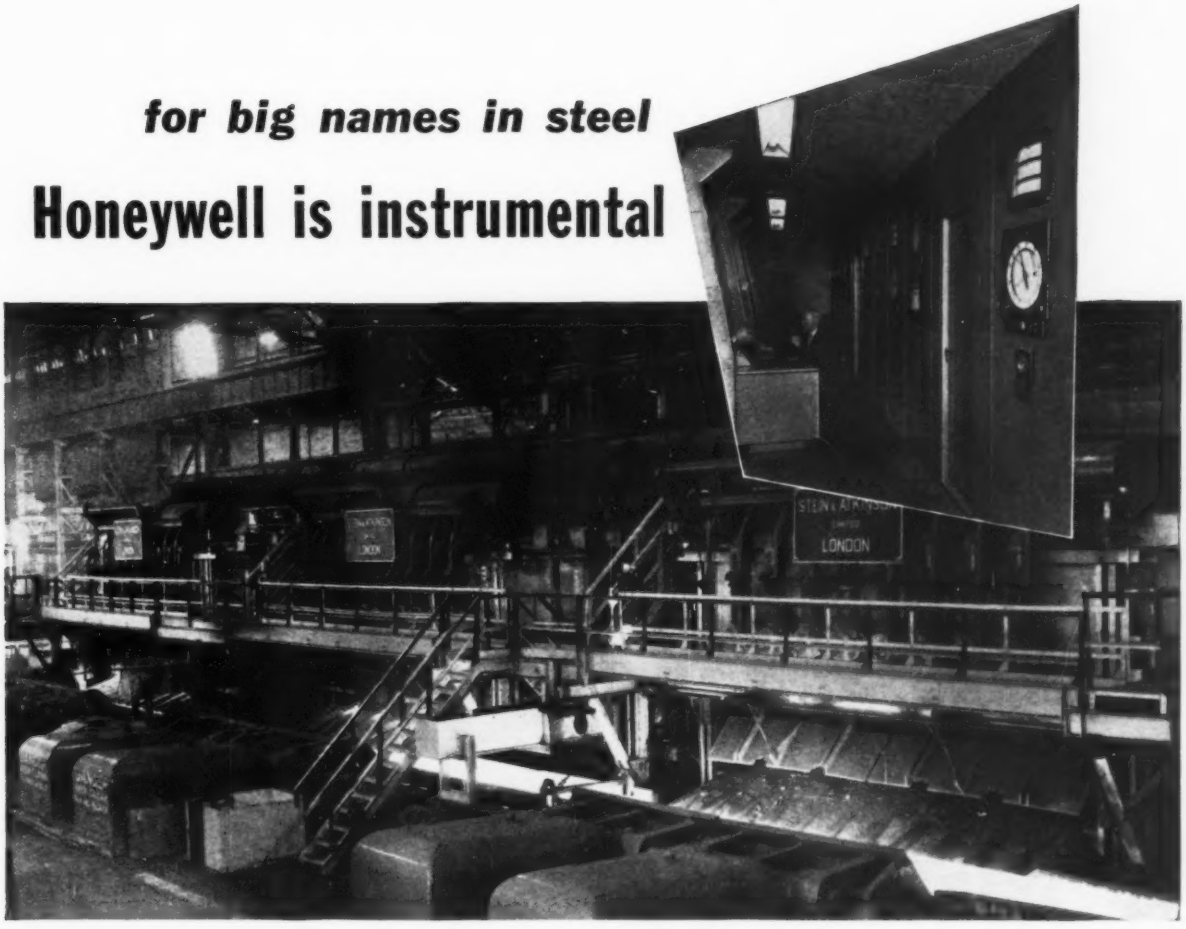

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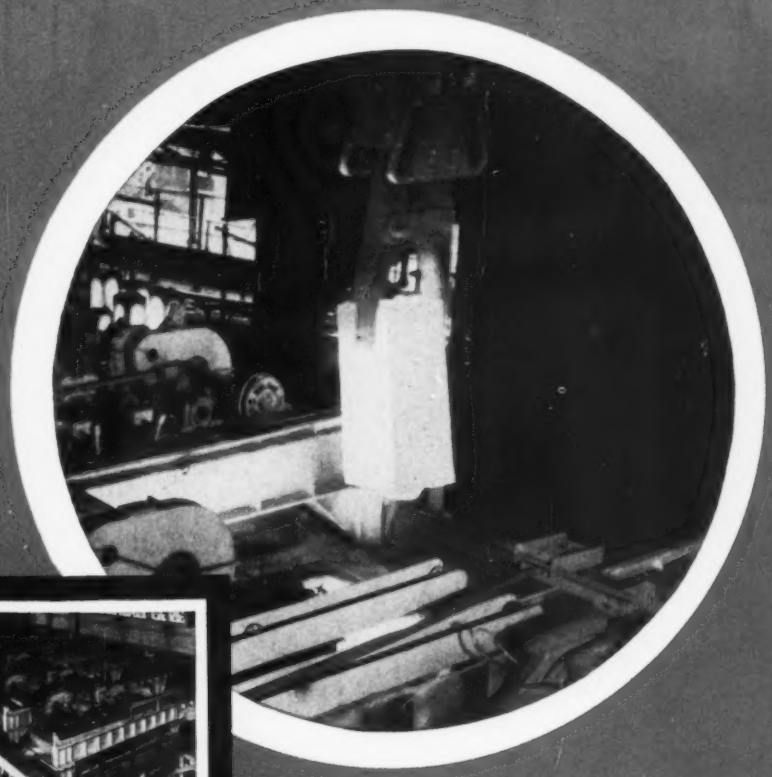

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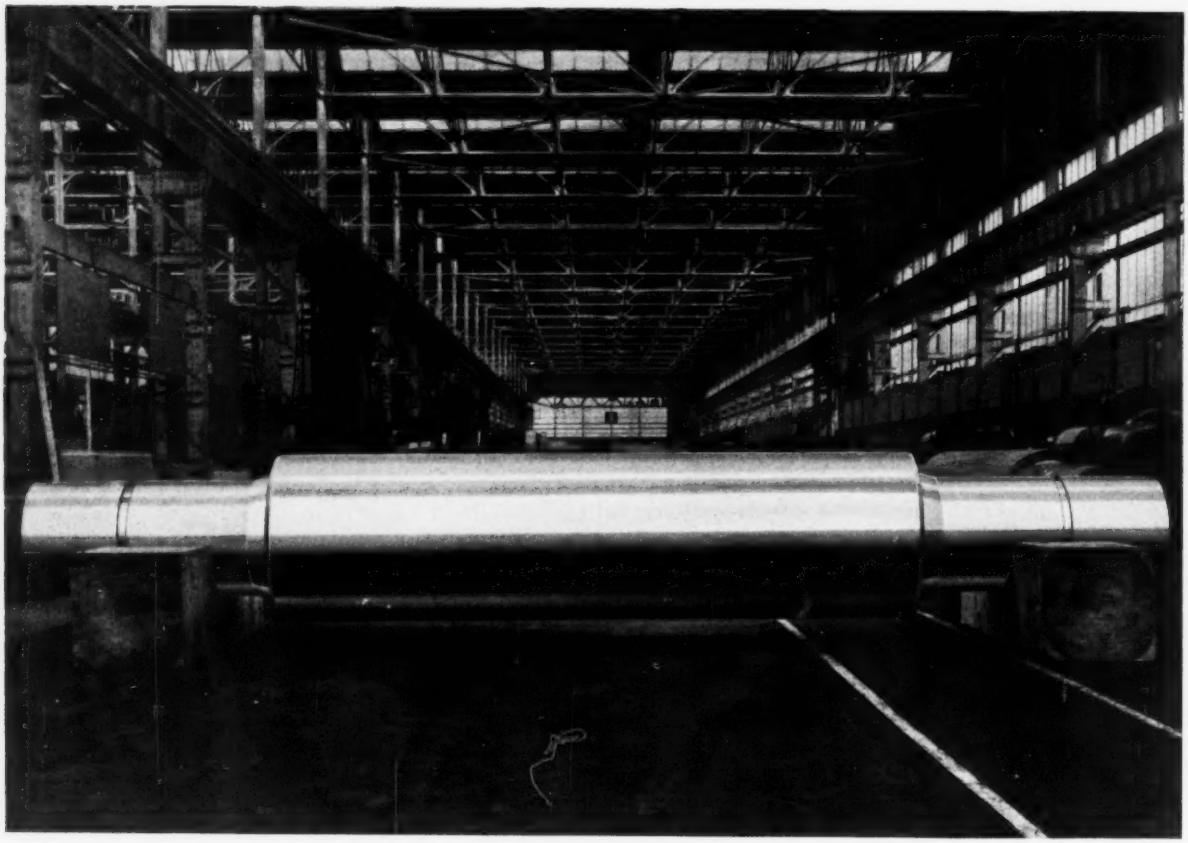

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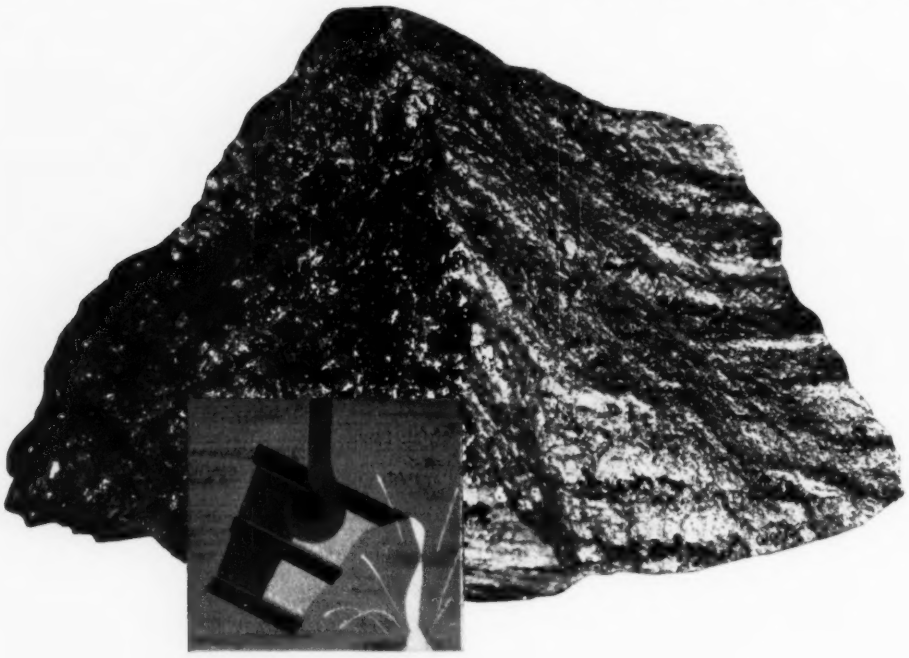

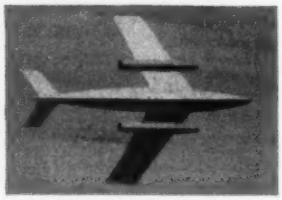

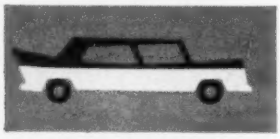

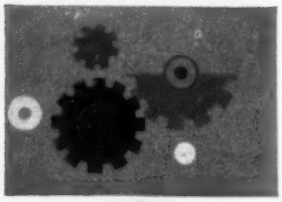

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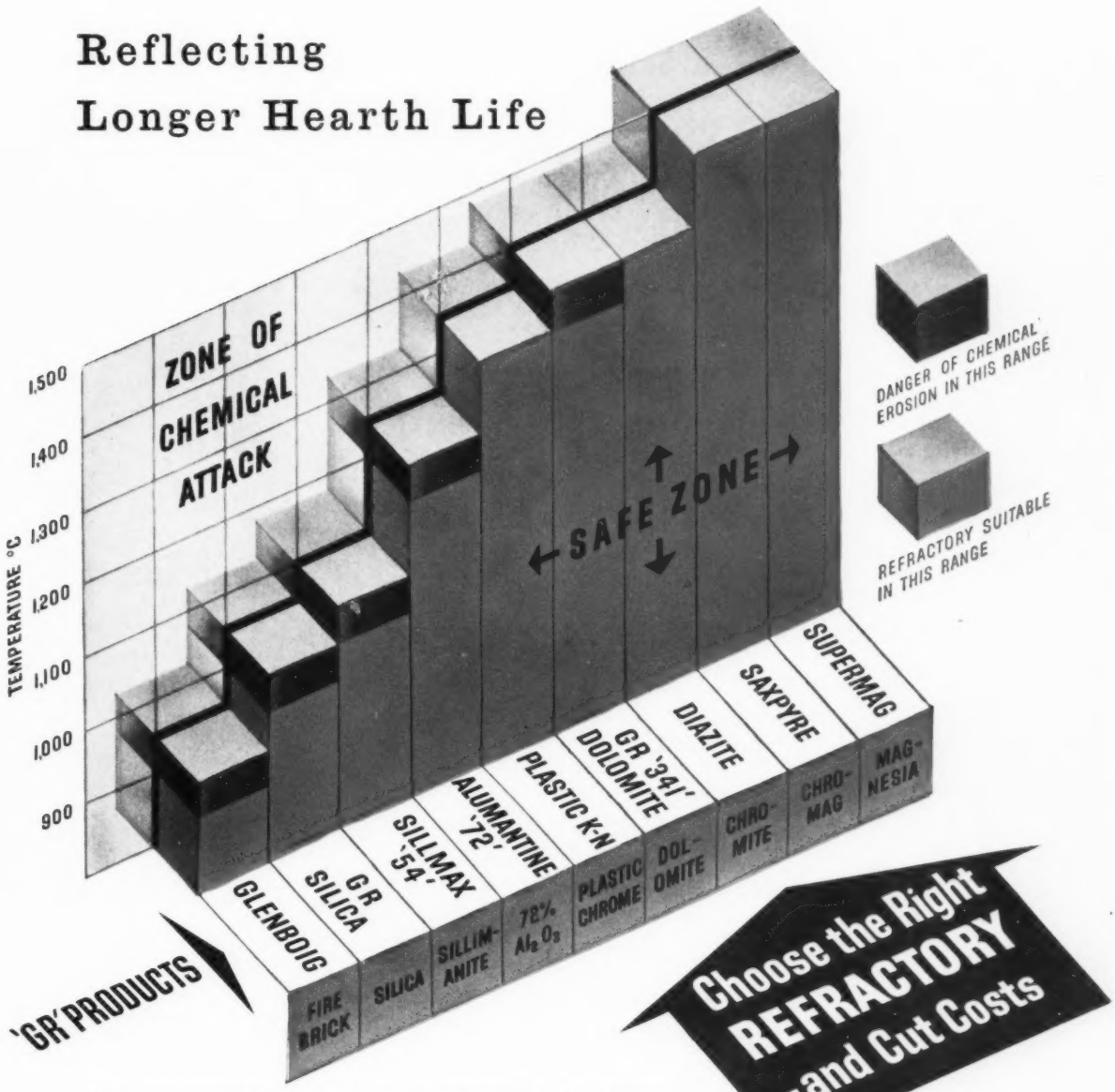

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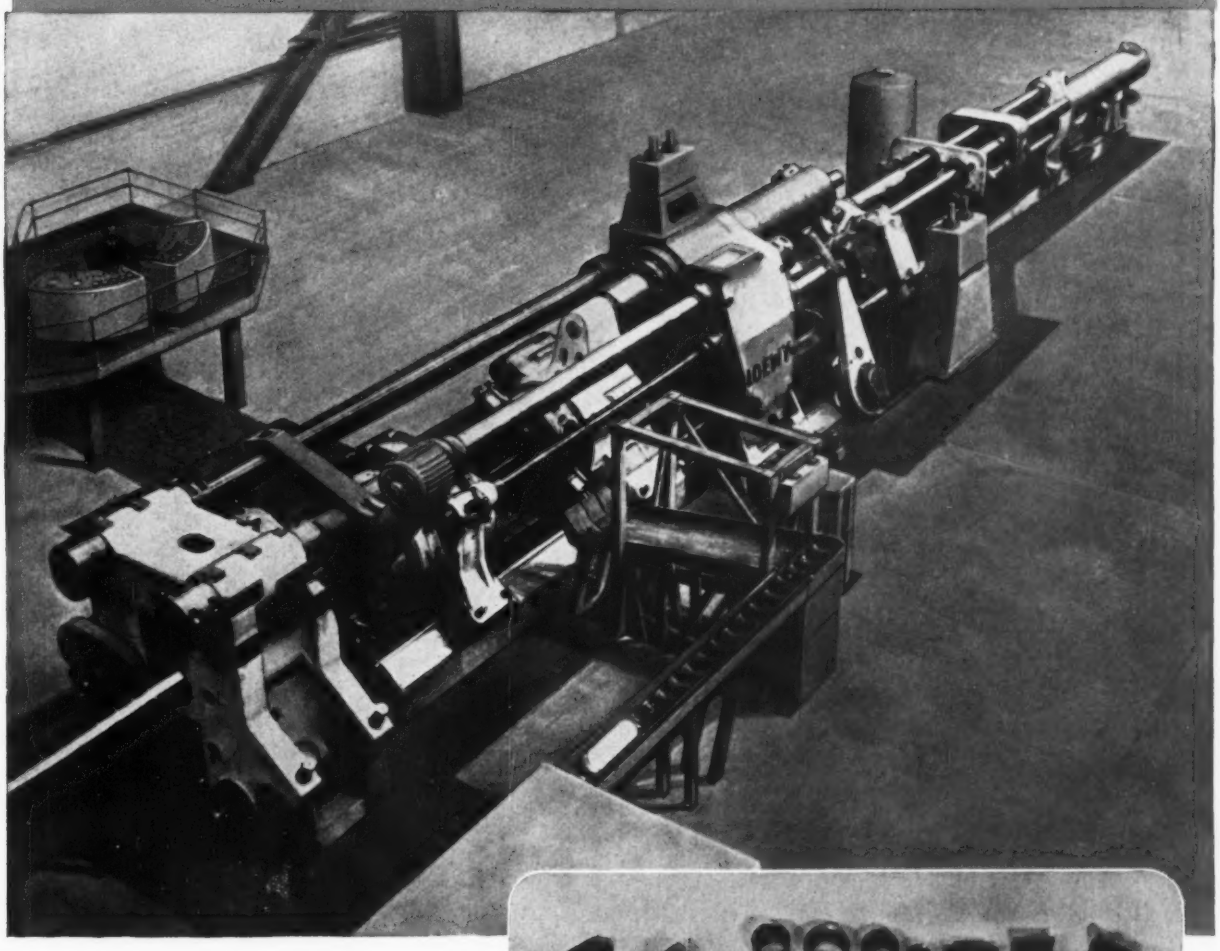

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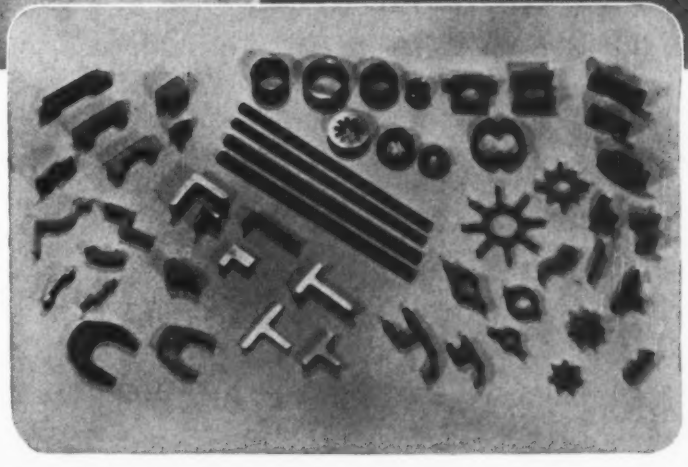

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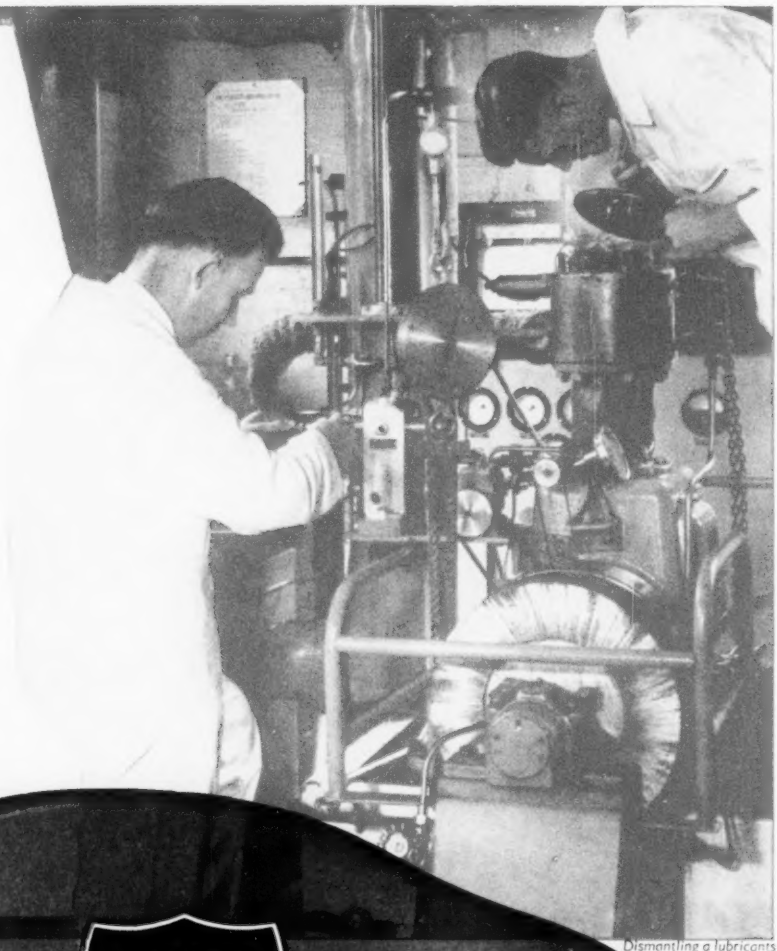

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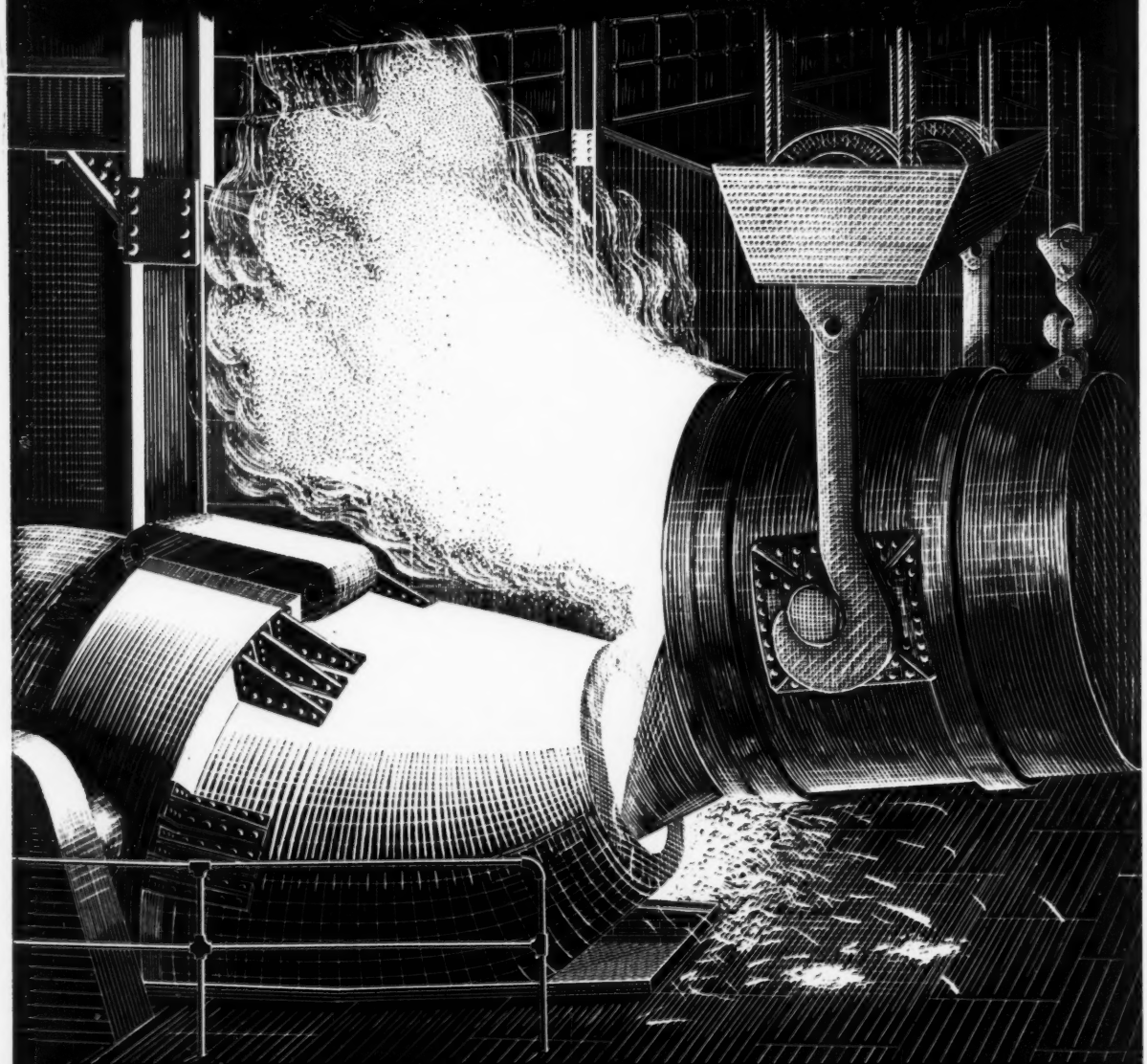

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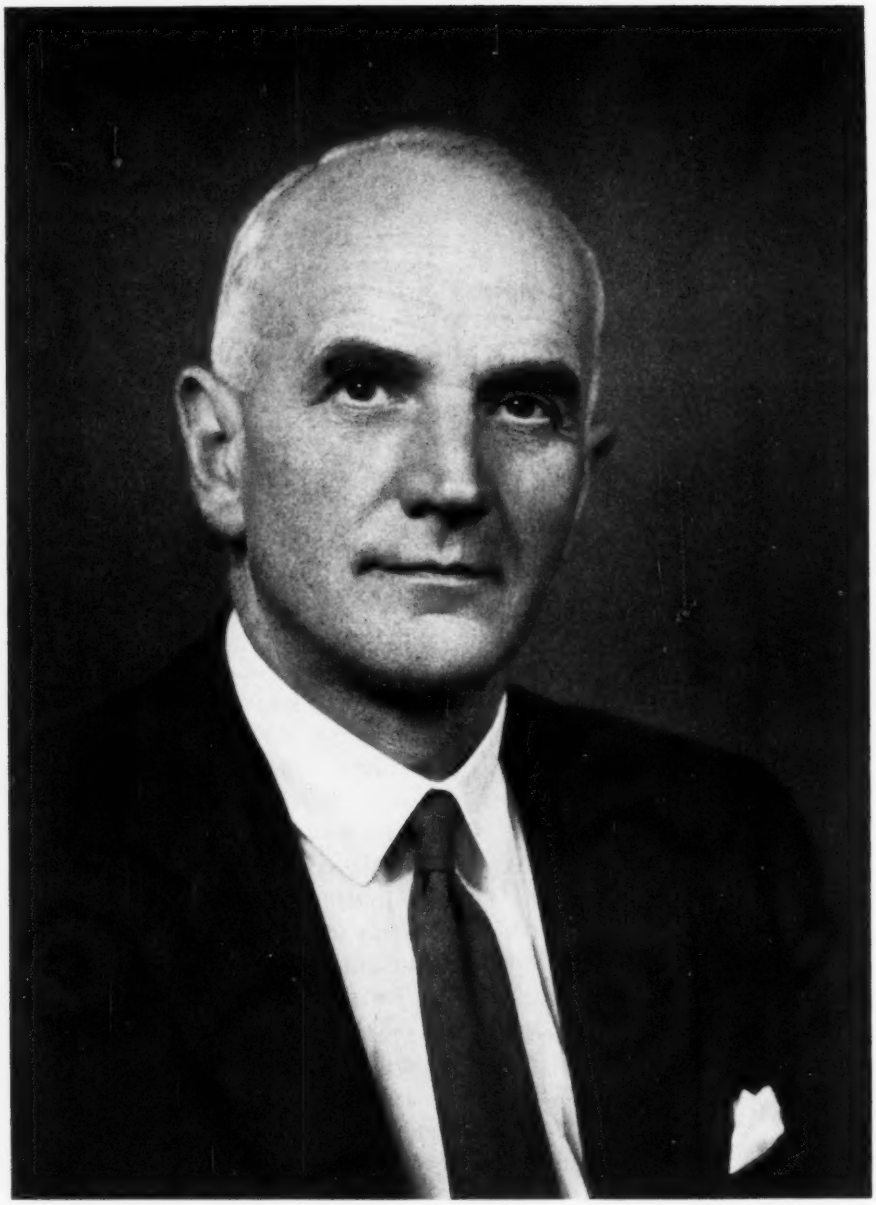
G. L. BAILEY, C.B.E., M.Sc., F.I.M.

GEORGE LEO BAILEY was educated at the King Edward VI Grammar School, Five Ways, Birmingham, and the University of Birmingham, where he graduated in metallurgy and in 1922 was awarded an M.Sc. degree for postgraduate work carried out under a Bowen Research Scholarship.

He then joined the metallurgy branch of the Research Department, Woolwich, where he was engaged on work sponsored by the British Non-Ferrous Metals Research Association on the casting of strip brass ingots. These investigations brought Mr Bailey into close contact with the BNFMRA and in 1930 he joined that Association as head of its development department. In 1942 he became deputy-director and in 1944 director. He was appointed a C.B.E. in 1952.

Mr Bailey has published many papers covering not only the investigation on brass strip ingot casting, but also on alloys resistant to sea-water corrosion, the effects and elimination of impurities in copper, and a variety of other subjects. With R. Genders he is author of a book 'The casting of brass ingots'.

Mr Bailey has served on a large number of committees including those of the Admiralty, the Ministry of Supply, the British Standards Institution, and the National Engineering Laboratory. After long service on the Council of The Institute of Metals he was elected President of that Institute for 1959–60. He is a founder member and Past-President of The Institution of Metallurgists, and a member of Council of the Institute of British Foundrymen. He joined The Iron and Steel Institute in 1945 and this year, as President of The Institute of Metals, he serves as an honorary member of Council.



G. L. Bailey, C.B.E., M.Sc., F.I.M.

Honorary Member of Council, 1959–60

The effects of neutron irradiation on the properties of iron and steels

D. R. Harries, B.Sc., Ph.D.

SYNOPSIS

The principal mechanisms of radiation damage in non-fissile metals are summarized and the terms used in irradiation experiments defined. Neutron irradiation effects on the mechanical properties of single and polycrystalline pure iron are described and the effects on the properties of ferritic and austenitic steels are detailed. The extent to which the exchanges in mechanical properties are affected by the irradiation and metallurgical variables are reviewed. Results on the annealing of radiation damage are considered and the available data on the mechanism of the radiation embrittlement surveyed. Finally, the present position and the future work required to further our understanding of radiation damage in steels are summarized. 1705

INTRODUCTION

EVER SINCE Wigner[1] first pointed out the possibility of damage to solids as a result of reactor-induced changes, considerable effort has been directed towards determining the effects of irradiation on the properties of reactor materials.

However, it is only recently that attempts have been made to study systematically the effects of irradiation on the properties of metals and alloys used as components not directly related to the nuclear reaction. Examples are the pressure vessel, which houses the entire reactor, fuel-element cladding, thermal shields, liner tubes for fuel-element channels, pressure tubes, and irradiation test loops. It is desirable to construct the pressure vessel and some of the other components from conventional engineering materials such as steels.

In a reactor, the use of a steel is dependent not only on its pre-irradiated mechanical properties, corrosion resistance to the reactor coolant, weldability, and acceptable nuclear properties, but also on the extent of the property changes induced by bombardment with nuclear radiation. Of particular interest are the tensile properties, toughness or impact strength, and creep resistance.

The elastic interaction of energetic radiation and matter results in radiation damage in a non-fissile metal as follows:

(i) Vacancies: vacant lattice sites may be created by collisions of neutrons with the atoms in a solid lattice. The energy transferred in these collisions is generally large enough to allow the knocked-on atom to produce additional vacant lattice sites by further collisions. Thus, for each initial neutron–atom collision, a cascade of collisions resulting in vacancies is initiated.

(ii) Interstitials: the atoms that are displaced from their equilibrium positions in the lattice will stop in interstitial or non-equilibrium positions unless they immediately recombine with an adjacent vacant lattice site.

(iii) Thermal spikes: since only a small part of the energy of the primary knocked-on atom is stored in the form of vacancies and interstitials, the remainder is released as increased atomic vibrations in a region of about 40 atomic spacings across and containing about 60000 atoms. The temperature in this region rises to about 4000°C and the material behaves more like a liquid than a solid for the time it takes the thermal pulse to disperse ($\sim 10^{-12}$ s).

(iv) Impurity atoms: these may be introduced through neutron capture and radioactive decay. The number introduced is generally small and, in non-fissile metals suitable for reactor applications the effect may be ignored in relation to other damage effects unless the integrated neutron dose attains a value of 10^{22}–10^{23} n/cm^2.

High-energy neutrons are the nuclear particles in a reactor which cause most of the damage in non-fissile metals because the energy of each is very large relative to the energy required to create a vacancy–interstitial pair (about 30 eV). Damage by other nuclear radiations such as β-particles and γ-rays is negligible compared with that due to fast neutrons, as the momentum which can be transferred to a lattice atom from such

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TABLE I Tensile properties at room temperature of irradiated high-purity iron,[5] irradiation temperature 95°C (max)

Strain rate, min^{-1}	Dose, n/cm^2 >1 MeV	YS, lb/in^2	UTS, lb/in^2	Total elongation, %	Uniform elongation, %
0·05	0	16800	34400	59·5	42
0·05	$3·6\times10^{19}$	41100	40700	29·5	11
2	0	26600	37800	54·0	31
2	$3·6\times10^{19}$	48700	•	...	0

• Load decreased continuously after initial yielding

radiations is small. Slow neutrons may be absorbed into the nucleus of the atom resulting in the formation of impurity atoms which may cause radiation damage indirectly (*but see* (iv) above).

The rates of neutron bombardment or the neutron-flux intensities in reactors are measured in nv where n=neutrons/cm³ in the incident beam and v=velocity in cm/s. The neutron-flux intensity varies not only from reactor to reactor but also from position to position in the core of a given reactor. The maximum flux intensity in BEPO is about 10^{12} n/cm²/s and in DIDO about 10^{14} n/cm²/s. The integrated neutron flux (nvt) is the number of neutrons incident per unit area for the time the specimen is exposed; thus, a flux intensity of 10^{14} n/cm²/s for 1 year (3×10^7 s) is equivalent to an integrated flux of 3×10^{21} n/cm².

Thermal or slow neutrons have energies of about 0·025 eV whereas fast neutrons are of 1 MeV at least or 4×10^7 times more energetic than thermal neutrons. Structural materials in a reactor are thus bombarded with neutrons having energies in the range 0·025 eV to >1 MeV, but since the measurement of the complete neutron spectrum in a position within a reactor is a difficult and tedious task, the present general method of reporting neutron fluxes is to quote the thermal flux and the fast flux above some threshold energy, usually 1 MeV.

Cottrell[2] has already described the basic theory and the effects of neutron irradiation on metals and alloys, and the particular case of neutron bombardment of steels has been discussed by Pugh.[3] This paper will be primarily confined to a review of the experimental results on the effects on the mechanical properties of iron and steels. Except where otherwise stated in the text, all the results were obtained in post-irradiation tests.

TABLE III Tensile properties of irradiated ASTM A212B steel,[12] irradiation temperature 95°C (max)

Dose n/cm^2, >1 MeV	Strain rate, min^{-1}	YS $lb/in^2\times10^3$	UTS, $lb/in^2\times10^3$	R. in A., %	Uniform elongation, %
0	0·05	51·4	75·1	62	19
0	0·05	47·3	75·0	64	23
0	0·05	51·6	76·1	67	24
10^{19}	0·05	65·4	80·8	68	18
10^{20}	0·05	94·9	97·1	28	5·4
10^{20}	0·05	92·6	97·0	24	5·6
0	0·5	50·7	76·7	64	23·2
0	0·5	52·6	78·8	58	20·2
10^{20}	0·5	98·5	100·1	32	4·5
10^{20}	0·5	94·5	97·8	35	12

PURE IRON

Kunz and Holden[4] irradiated single crystals, grown by the strain-anneal method to a total thermal flux of 10^{18} n/cm² at 50°C (max) and determined the subsequent effect on the tensile properties at RT. The flow stress was increased by 90–100% after irradiation but after about 16% elongation the stress/strain curves of the irradiated and unirradiated control specimens came together. The tensile strength of the irradiated and unirradiated crystals was the same within experimental error but the irradiated crystals fractured at a greater elongation.

It was also established that the material became less sensitive to radiation if it was first hardened by plastic working:

Elongation applied before irradiation, %	0	5	10	15	17
Increase in yield stress due to irradiation, lb/in^2	3400	1650	1200	500	0

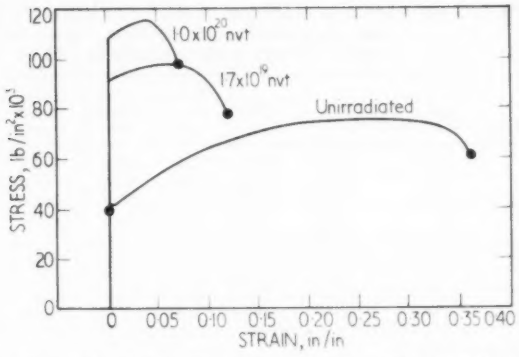
Berggren and Wilson[5] noted that the properties of irradiated and unirradiated polycrystalline high-purity iron were markedly affected by strain rate. The iron analysed at 0·004%C–0·0038%O_2–0·000073%N_2–0·0028%Ni–0·09%Si–other metallic impurities <0·001%, and was annealed at 620°C for ½ h and water quenched before testing. The results are summarized in Table I.

At a strain rate of 0·05/min the irradiated iron showed a reduced uniform (but not post-necking) elongation. The load/elongation curve was unusual in that the yield stress exceeded the conventional ultimate tensile stress. At a strain rate of 2/min the

TABLE II Changes in hardness of plain carbon steels after irradiation[3]

Steel	Specified composition	Condition	Integrated neutron flux, 10^{19} n/cm² Slow	Fast (>1 MeV)	Irradiation temperature, °C	Brinell hardness* Before	After
SAE–1018	0·15–0·20%C; 0·6–0·9%Mn; 0·040%P; 0·050%S; 0·30%Si (max)	Annealed	1	...	230–260	174	183
		Annealed	1	...	230–260	156	168
		Hardened	1	...	230–260	241	247
		Annealed	2	0·7	21–60	138	161
		Hardened	2	0·7	21–60	237	243
SAE–1042	0·40–0·47%C; 0·6–0·9%Mn; 0·040%P; 0·050%S; 0·30%Si (max)	Annealed	1	...	230–260	201	207
		Annealed	1	...	230–260	236	270
		Hardened	1	...	230–260	430	444
SAE–1095	0·90–1·05%C; 0·3–0·5%Mn; 0·040%P; 0·050%S; 0·30%Si (max)	Annealed	1	...	230–260	297	311
		Hardened	1	...	230–260	542	550
		Annealed	2	0·7	21–60	290	315
		Hardened	2	0·7	21–60	535	535
SAE–1113	0·10–0·16%C; 1·0–1·3%Mn; 0·045%C; 0·24–0·33%S; 0·30%Si (max)	Annealed	1	...	230–260	195	217
		Hardened	1	...	230–260	190	195
SAE–1141	0·37–0·45%C; 1·35–1·65%Mn; 0·045%P; 0·08–0·13%S; 0·30%Si (max)	Annealed	1	...	230–260	220	255
		Hardened	1	...	230–260	421	430

• Converted from Rockwell hardness scales



1 *Conventional stress/strain curves for fine grain ASTM–A–212–B carbon–silicon steel irradiated at 95°C (max), after Berggren and Wilson*[5]

irradiated iron showed no observable uniform elongation, virtually all the elongation occurring by necking.

Bruch and McHugh[6] have shown that the hardness of high-purity iron irradiated at 80°C increases progressively with neutron dose up to 8×10^{18} n/cm² (>1 MeV). After this exposure the iron hardened by 42 BHN. After $1{\cdot}1\times10^{20}$ n/cm² (>1 MeV) the total hardness increase was 43 BHN, indicating saturation.

Bruch *et al.*[7, 8] observed that a yield point is produced in the stress/strain curves by irradiation and that an exposure temperature of 300°C does not effectively reduce the irradiation effects:

	Yield stress, lb/in²
Unirradiated	13800
10^{17} n/cm²(>1 MeV) 80°C	21600
10^{17} n/cm²(>1 MeV) 150°C	22200
10^{17} n/cm²(>1 MeV) 300°C	19800

FERRITIC STEELS

Hardness

Sutton and Leeser[8] investigated radiation-hardening effects in the carbon steels listed with the specified compositions and results in Table II. These results show that appreciable hardening can be obtained by irradiation. The radiation-induced hardening is greater for the fully annealed materials than for those initially hardened, and is not a direct function of carbon content. Further, the hardness increases after irradiation at RT are greater than after irradiation at high ambient temperatures (~260°C).

Bleiberg[9] found that the hardness increases shown by an ASTM–A212B steel (0·29%C–0·75%Mn–0·16%Si–0·020%P–0·028%S) in the normalized and stress-relieved condition saturated after irradiation to 3×10^{19} n/cm² (>1 MeV) at 38°C (max). The hardness increased from the pre-irradiated value of 65 to 80 Rockwell 30T regardless of the dose from 3×10^{19} to $2{\cdot}1\times10^{20}$ n/cm² (>1 MeV). However, Baldwin[10, 11] observed that the hardness of an annealed ASTM–A201 steel (0·24%C–0·8%Mn–0·15–0·30%Si, specified analysis) irradiated at 150–205°C increased progressively to a dose of $4{\cdot}3\times10^{20}$ n/cm² (>1 MeV).

Tensile properties

Effect of integrated neutron-flux dose

The tensile properties of irradiated ASTM–A212B steel (0·24%C – 0·81%Mn – 0·248%Si – 0·020%P – 0·040%S) normalized from 1040°C to produce a ferrite grain size ASTM5 have been reported by Wilson and Berggren[12] and are shown in Table III.

TABLE IV Tensile properties of irradiated alloy steels[5] Strain rate 0·05/min, irradiation temperature 95°C (max)

Steel	Dose, n/cm² (>1 MeV)	YS, lb/in²×10³	UTS, lb/in²×10³	Total elongation, %	Uniform elongation, %
8·5% Nickel	0	91·8	119·0	29·5	21·5
	$1{\cdot}7\times10^{19}$	138·0	148·0	18·0	11·0
	10^{20}	183·0	184·0	5·5	2·0
Carilloy T-1	0	120·0	129·0	14·0	7·9
	$1{\cdot}7\times10^{19}$	170·0	171·0	4·5	0·5
	10^{20}	186·0	187·2	3·8	0·3

The yield stress is elevated to a greater extent than the ultimate tensile stress by neutron irradiation and these approach very closely. The rate of work-hardening is low, and after 10^{20} n/cm² plastic deformation before necking is small. This type of steel which shows a characteristic yield point at the onset of plastic deformation unirradiated, does not show one after irradiation (Fig.1).

In contrast to the behaviour of pure iron, a tenfold increase in the strain rate had little effect on either the unirradiated or the irradiated properties of the steel, excepting for the reduction of area values in the 10^{20} n/cm² irradiated samples which are slightly greater for those pulled at the higher strain rate.

Neutron irradiation effects on the tensile properties of high-alloy ferritic steels reported by Berggren and Wilson[5] are given in Table IV. The nominal 8·5% nickel steel (8·58%Ni–0·10%C–0·76%Mn–0·23%Si) was normalized and tempered and the high yield strength steel, Carilloy T–1 (0·1–0·2%C–0·6–1·0%Mn – 0·15–0·35%Si – 0·7–1·0%Ni – 0·4–0·8%Cr – 0·4–0·6%Mo – 0·03–0·10%V – 0·15–0·50%Cu – 0·002–0·006%B)[13] was quenched and tempered.

The radiation-induced changes follow the trends shown by polycrystalline high-purity iron in that there is a marked increase in yield stress with a lesser increase in ultimate tensile strength accompanied by a decrease in the elongation to fracture. A greater amount of radiation damage would be expected for a given integrated neutron dose in a boron-containing steel such as Carilloy T–1 than in a boron-free steel because of the $B^{10}+n\rightarrow Li^7+He^4$ reaction. The 'fragments' have a total kinetic energy of 2·8 MeV which will therefore displace a large number of atoms. The results given in Table IV indicate that the changes in yield and ultimate tensile stresses of Carilloy T–1 after irradiation to $1{\cdot}7\times10^{19}$ n/cm² are greater than those for the 8·5% nickel steel but after 10^{20} n/cm² the magnitude of the property changes are less. Enhanced radiation damage due to boron may be overshadowed by the greater radiation stability of the quenched and tempered, fine-grained bainitic structure of the Carilloy T–1 steel.

Effect of irradiation temperature

Wilson and Berggren[12] have observed that irradiation to 10^{19} n/cm² (>1 MeV) at 300°C resulted in a smaller increase in yield stress (50000 to 56800 lb/in²) and a greater increase in ultimate tensile strength (75000 to 83900 lb/in²) of an ASTM–A212B steel than after a similar irradiation dose at 95°C max (*see* Table III). The reduction in area and the uniform elongation values were also lower for the specimens irradiated at

TABLE V Effect of irradiation temperature on the RT tensile properties of an ASTM-A212B steel[16]

Dose, n/cm² >1 MeV	Temp. of irradiation, °C	YS, lb/in²×10³	UTS, lb/in²×10³	Uniform elongation, %
0	...	40	75	25
2×10^{19}	80	92	98	6
2×10^{19}	295	76	102	9
2×10^{19}	360	61	90	12
2×10^{19}	405	56	84	14

the higher temperature. It appears from these results that partial annealing of the radiation damage responsible for one mechanical property may take place more or less independently of another mechanical property at a given temperature of irradiation.

Baldwin[10, 14, 15] has noted that lesser changes are produced in the room-temperature tensile properties of an ASTM–A302–B steel (0·25%C–1·38%Mn–0·24%Si–0·45%Mo) in the normalized and stress-relieved condition (ASTM grain size 8) after irradiation to a dose of 3×10^{18} n/cm² (>1 MeV) at 371°C than at 260°C. This does not confirm Wilson and Berggren[12] in that partial annealing of the radiation damage during irradiation at 371°C results in lesser changes in all the tensile properties and one property is not affected differently from another.

The tensile properties of a series of steels after irradiation in the range 80–415°C have been reported by Wilson.[16] His results on an ASTM–A212B steel are given in Table V.

Exposure at 405°C is thus insufficient to cause complete annealing of the radiation damage.

Effect of grain size

Grain-size effects on radiation stability have been studied by Wilson and Berggren[5, 12] using an ASTM–A106 steel. One heat was killed with aluminium, the analyses and grain sizes of the two grades being as follows:

Coarse grain (ASTM2):
0·24%C; 0·72%Mn; 0·018%P; 0·023%S; 0·20%Si
Fine grain (ASTM7):
0·24%C; 0·70%Mn; 0·019%P; 0·020%S; 0·19%Si
Al fine-grain practice

The steels were normalized at 925°C for 1 h and the RT tensile test results before and after irradiation are given in Table VI.

Although the results indicate that the fine grain steel is less sensitive to radiation damage, it is not possible to conclude whether the superiority is due solely to the fine grain or to the scavenging of the nitrogen in the steel by the aluminium or to a combination of both factors.

TABLE VI Tensile test results on fine- and coarse-grained ASTM–A106 steel[5, 12] Strain rate 0·05/min, irradiation temperature 95°C (max)

Dose, n/cm² (>1 MeV)	YS, lb/in²×10³	UTS lb/in²×10³	Total elongation, %	Uniform elongation, %	Reduction in area, %
Fine grain ASTM 7					
0	57·7	75·4	...	18·8	67
10^{19}	72·6	78·4	...	23·2	70
0	47·3	73·6	34	24·5	...
10^{20}	96·5	102·0	11·5	4·5	...
Coarse grain ASTM 2					
0	50·4	85·0		20·2	67
10^{19}	71·6	89·5		16·0	68
0	47·6	83·0	29	19·0	...
10^{20}	116·0	121·0	6·5	1·5	...

TABLE VII Effects of irradiation on the tensile properties of steels of different carbon contents[19] (steels normalized from 925°C and irradiated at <95°C)

Steel	*nvt* (>1 MeV)	YS, lb/in²	UTS, lb/in²	Uniform elongation, %	Necking elongation, %	Total elongation, %
1	0	57200	78000	17·4	10·8	28·2
	$1·7\times10^{19}$	87600	90000	3·6	10·4	14·0
	10^{20}	85800	101200	7·8	5·8	13·6
2	0	27600	51100	29·5	15·5	45·0
	$1·7\times10^{19}$	82600	82600	0	9·5	9·5
	10^{20}	97600	98500	0·5	8·0	8·5
3	0	45600	55500	25	10·0	35·0
	$1·7\times10^{19}$	82900	80600	0·5	10·0	10·5
	10^{20}	98400	98000	1·0	6·5	7·5

Steel	Steel analysis, % C	Mn	P	S	Si	Al	Cu	Ti	Zr
1	0·21	0·09	0·009	0·015	0·18	0·009	...	0·14	...
2	0·07	0·15	0·011	0·029	0·07	0·048	0·39	0·42	...
3	0·05	0·08	0·006	0·018	0·06	0·30	0·39	...	0·33

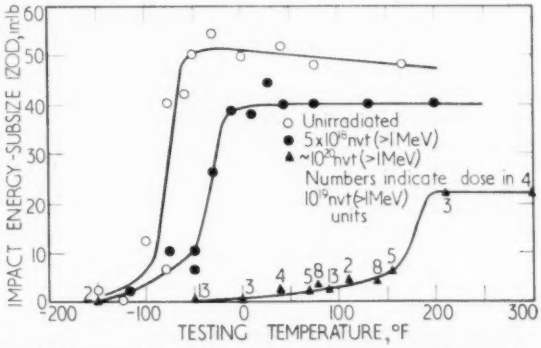
The superior resistance of fine-grained steel to radiation damage has also been observed experimentally by Churchman, Mogford, and Cottrell[17] and the results have been summarized by Hull.[18] Grain sizes of 2000 and 500 grains/mm² were produced by heat-treatment in tensile specimens of an En2 steel (0·15%C–0·59%Mn–0·12%Si) which were irradiated at 50–100°C and tested at −196°C. Whereas all the unirradiated samples were ductile, the coarse-grained samples were brittle after a dose of $1·5\times10^{19}$ n/cm² but the fine-grained specimens showed some ductility even after 9×10^{19} n/cm².

Effect of carbon content

Recent studies at the Oak Ridge National Laboratory[19] suggest that fine grain size alone does not make a steel more radiation resistant.

Table VII shows the analyses and the effects of irradiation on the tensile properties of three experimental heats of low-manganese steels which are all fine-grained and essentially ferritic. Two of the steels are of low carbon content while the third has a higher carbon content more akin to the boiler-quality steels.

The low-carbon steels show lower uniform ductility



2 *Subsize notch-bar impact strength of hot-rolled ASTM–A–212–B carbon–silicon steel irradiated at 95°C (max), after Berggren and Wilson*[5]

TABLE VIII Irradiation effects on the impact properties of En2 steel[17]

Integrated neutron flux, n/cm² (thermal)	Ductile/brittle transition temperature, °C	Maximum (ductile) energy, ft lb
Unirradiated	−26	41
$2{\cdot}5\times10^{17}$	−20	25
$9{\cdot}5\times10^{17}$	−6	23
$1{\cdot}9\times10^{19}$	+36	17

after a dose of $1{\cdot}7\times10^{19}$ n/cm² (>1 MeV). It has been tentatively suggested that ferrite alone rapidly loses its ductility upon irradiation, and that the carbide platelets in the higher-carbon steels give greater resistance to radiation-induced loss of ductility.

Impact properties

Steels which normally have a tendency to brittle failure may become embrittled by irradiation as measured by the effect on the transition temperature below which the steel is brittle. The effect was first observed by Sutton and Leeser[8] who obtained increases of 95°C in the transition temperature and decreases of 29% in the maximum (ductile) energy of a plain carbon steel irradiated at 50°C to an integrated flux of 8×10^{19} n/cm² (>1 MeV). Later investigations have confirmed these observations. Figure 2 shows graphically the effects of neutron irradiation on the notch-impact properties of a mild steel.

Effect of integrated neutron flux dose

Changes in transition temperature of a plain carbon structural steel (En2: 0·15%C–0·59%Mn–0·12%Si; 2000 grains/mm²) with respect to low values of the integrated neutron flux have been obtained by Churchman *et al.*[17] Subsize specimens were irradiated at 50°–100°C and tested in a balanced impact machine. The results are given in Table VIII.

The results show that marked changes in properties are obtained after integrated neutron doses as low as $2{\cdot}5\times10^{17}$ n/cm². This threshold dose may well be dependent on both the temperature of irradiation and the type of steel. Leeser and Deily[20] have reported an increase of 14°C in the Charpy impact transition temperature and a decrease of 5 ft/lb in the maximum (ductile) energy of a plain carbon steel irradiated to 2×10^{17} n/cm² (>1 MeV) at 260°C.

The effects of larger irradiation doses on the impact properties of substandard specimens of an ASTM–SA–212B steel (0·29%C–0·75%Mn–0·16%Si) and an ASTM–A201 steel (0·17%C–0·57%Mn–0·21%Si; Al killed) have been investigated by Bleiberg[9] and Trudeau[21] respectively. Their results are summarized in Table IX.

Trudeau[22] has irradiated impact specimens of a range of ferrites designed to determine the effect of manganese, nickel, chromium, and molybdenum on the radiation stability. Although large increases in transition temperature were obtained after irradiation, the maximum energy absorption in the ductile region of the transition curves showed no change.

TABLE X Increase in transition temperature calculated from Cottrell's formula compared with observed values

Steel	Dose, 10^{18} n/cm²	ΔT calculated, °C	ΔT observed, °C	Reference
En2	0·25	11	5–10	
	0·95	17	10–25	17, 24
	1·9	21	5–10	
	15	43	30–35	
	19	47	50–65	
	57	67	70–75	
	93	79	55–75	
ASTM–A212	2	22	22	8
	80	78	80	
0·34%C Al killed	2	22	11	8

Cottrell[23] deduced empirically from experimental data that the increase in tensile yield stress ($\Delta\sigma$) due to irradiation is roughly proportional to the cube root of the total neutron dose ϕ. Using this in combination with his theoretical relationship between $\Delta\sigma$ and the increase in transition temperature ΔT, Cottrell obtains:

$$\Delta T = 17{\cdot}5\phi^{\frac{1}{3}} \quad \ldots\ldots(1)$$

where ϕ is in units of 10^{18} n/cm².

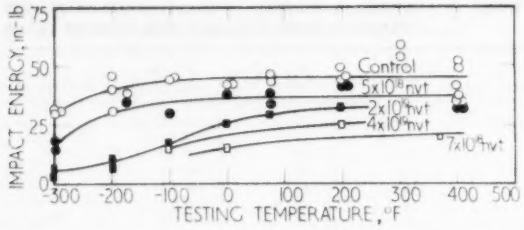
This formula is compared with various results on radiation embrittlement in Table X.

The predicted and observed increases in transition temperature are broadly in agreement. The results of Bleiberg[9] and other workers and Trudeau[21] have not been included in Table X since they refer only to neutrons above 1 MeV and 500 eV respectively. Equation (1) is based on measurements of thermal flux in positions where the thermal and epithermal fluxes are about equal. Bleiberg[9] observed increases in transition temperatures about twice these given in the table; this is reasonable if the flux above 1 MeV is one-eighth of the thermal flux. The aluminium-killed steel is less sensitive than equation (1) predicts which is in agreement with Cottrell's relation for the dependence of transition temperature on grain size (*see* later).

The impact properties of ferritic alloy steels also show a degradation after irradiation. These steels generally do not show a ductile/brittle transition temperature above −196°C before or after irradiation. However, an ASTM–446 ferritic stainless steel (0·35%C max–1%Mn–1%Si–0·6%Ni max–23–27%Cr) irradiated at 95°C max to $>10^{20}$ n/cm² (>1 MeV) shows a transition temperature at 175–205°C whereas the unirradiated material showed no transition temperature between −185° and 300°C.[25] Increasing brittleness of these alloy steels is usually manifested as a lowering of the energy absorbed to fracture, which is

TABLE IX Changes in the impact properties of mild steels after neutron irradiation[9, 21] (temperature of irradiation 100°C max)

Steel	Condition	Dose, n/cm²	Transition temperature, °C Before	After	Change	Maximum (ductile) energy, ft lb Before	After	Change
ASTM–SA–212B	Normalized at 900°C 3 h. Stress relieved 635°C 1 h	3×10^{19} (>1 MeV)	−75 to +50	100–150		7·5	5	−2·5
		15–21×10^{19} (>1 MeV)		100–200		7·5	4	−3·5
ASTM–A201	Hot rolled	4×10^{19} (>500 eV)	−60	+25	85	7·5	7·0	−0·5
		6×10^{19} (>500 eV)	−60	+38	98	7·5	6·4	−1·1
		$1{\cdot}2\times10^{20}$ (>500 eV)	−60	+68	128	7·5	4·9	−2·6



3 *Subsize notched-bar impact strength of 8·5% nickel steel irradiated at 95°C (max), after Berggren and Wilson*[5]

progressive with increasing neutron dose. This is shown graphically for a normalized and tempered 8·5% nickel steel irradiated at 95°C (max) in Fig.3.

Effect of temperature of irradiation

Irradiation of plain carbon and low-alloy steels at high ambient temperatures (>300°C) generally produces lesser changes in impact properties than irradiation below 100°C. Typical results are quoted in Table XI.

However, recent work described by Wilson[16] shows that several factors (including composition, heat-treatment, etc.) govern the susceptibility of steels to radiation damage when irradiated at 300°C. Charpy V-notch specimens were machined from the following steel plates.

(i) ASTM–A–212B: 0·27%C–0·82%Mn–0·016%P–0·028%S–0·19%Si; Al killed; 6-in. plate normalized and stress relieved at 645°C.

(ii) ASTM–A–212B: 0·20%C–0·82%Mn–0·018%P–0·030%S–0·22%Si; $\frac{3}{4}$-in. plate, normalized.

(iii) ASTM–A–301B: 0·11%C–0·36%Mn–0·02%P–0·026%S–0·22%Si–0·98%Cr–0·47%Mo; 1-in. plate, furnace cooled from 925° to 595°C, then air cooled.

The transition temperatures and ductile energy values after irradiation to 5×10^{18} n/cm² (>1 MeV) at 80° and 300°C are given in Table XII.

The effect of irradiation temperature is not the same for the three steels. Steel (i) does not benefit from the elevated irradiation temperature; steel (ii) improved on the 300°C irradiation; and steel (iii) although deriving some benefit shows a greater loss of energy than the other steels. Both the type A–212 steels were fine grained and of similar composition except for carbon content. Each steel was normalized in the full thickness of the plate and thus the cooling rates were different.

TABLE XII Effect of irradiation at 80° and 300°C on the Charpy V-notch impact properties of steels[16]

Steel	Dose, n/cm²	Transition temperature, °C*	Max. (ductile) energy, ft lb
1	Unirradiated	10	92
	5×10^{18}, 80°C	75	>80
	5×10^{18}, 300°C	75	>80
2	Unirradiated	−40	40
	5×10^{18}, 80°C	20	34
	5×10^{18}, 300°C	−30	>35
3	Unirradiated	20	62
	5×10^{18}, 80°C	80	29
	5×10^{18}, 300°C	45	36

* Mid-range energy values

Burnett, Allen, and Harries[26] have reported that a dose of 4×10^{19} n/cm² (thermal) at 50° and 130°C produces increases of about 35° and 66°C respectively in the transition temperature of a low alloy steel (0·155%C – 0·18%Si – 1·24%Mn – 0·49%Cr – 0·28%Mo – 0·07%V) tested in slow bend. A similar temperature effect was exhibited by an aluminium-killed mild steel (0·14%C–0·11%Si–1·07%Mn)[27] but a silicon-killed plain carbon steel (0·24%C–0·15%Si–0·55%Mn) showed the same increase of 80°C in transition temperature when irradiated to 3×10^{19} n/cm² (thermal) at 50°, 85°, and 130°C respectively.[28] These results suggest that the temperature dependence of radiation damage may be a function of the amount of carbide and nitride formers in the steel.

Leeser and Deily[20] observed increases of 20° and 25°C in the impact-transition temperature of a plain carbon steel irradiated to dose of 2×10^{18} n/cm² (>1 MeV) at 220° and 305°C respectively. It was also found that the transition temperature of an aluminium-killed 0·34%carbon steel irradiated to 2×10^{18} n/cm² (>1 MeV) at 180°, 200°, and 220°C respectively was raised by 11°C in each instance. Baldwin[10, 14, 15] obtained increases of 18°C in the Charpy impact-transition temperature of a low-alloy steel (0·25%C–1·38%Mn–0·24%Si–0·45%Mo), after irradiation to $3\cdot7\times10^{18}$ (>1 MeV) at 260° and 371°C respectively. It is interesting to note from Baldwin's data that a 20-day treatment at 260°C, which is within the 'blue-brittle' range, increased the transition temperature

TABLE XI Effect of temperature on the impact properties of plain carbon and low-alloy ferritic steels irradiated to 5×10^{18} n/cm² (>1 MeV)[5]

Steel	Temperature of irradiation, °C	Transition temperature, °C Before	After	Change	Maximum (ductile) energy,* in. lb Before	After	Change
ASTM–A–106(1)	<95	10	16	+6	105	>60	<−45
	315	10	13	+3	105	>60	<−45
ASTM–A–106(2)	<95	−40	0	+40	110	>125	<+15
	315	−40	−27	+13	110	125	+15
ASTM–A–212B(3)	<95	−9	10	+19	78	67	−11
	315	−9	−9	0	78	84	+6
Carilloy T–1(4)	<95	−135	−27	+108	50	40	−10
	300	−135	−64	+71	50	50	0

Steel analysis, %									Treatment
	C	Mn	Si	Ni	Cr	Mo	V	Cu	B	
1	0·24	0·72	0·20	...	...	...	...	...	...	Normalized from 930°C, ASTM2
2	0·24	0·70	0·19	...	...	...	...	...	...	Normalized from 930°C, Aluminium fine-grain practice, ASTM7
3	0·28–0·33	0·9 (max)	0·15–0·30	...	...	...	...	...	...	Aluminium fine-grain practice
4	0·1–0·2	0·9 (max)	0·15–0·30	0·7–1·0	0·4–0·8	0·4–0·6	0·03–0·10	0·15–0·50	0·002–0·006	Quenched and tempered

*Sub-standard Izod specimens.

TABLE XIII Effect of grain size on the impact properties of irradiated ASTM–A106 steel[5]

ASTM grain size	Dose, n/cm² (>1 MeV)	Transition temp., °C Before	After	Max. energy, in. lb Before	After
2	5×10^{18}	+10	16	105	>60
	~10^{20}	+10	150	105	55
7	5×10^{18}	−40	0	110	>125
	~10^{20}	−40	75	110	65

more than irradiation at the same temperature. However, Wilson[16] believes that the flux quoted by Baldwin has been overestimated.

Effect of grain size

Berggren and Wilson[5] irradiated and tested substandard Izod impact specimens of two heats of an ASTM–A106 steel, one of which had been killed with aluminium to produce a fine grain size. The results of the impact tests after irradiation at 95°C (max) are given in Table XIII.

The unirradiated fine-grained steel shows a lower transition temperature and higher ductile energies than the coarse-grained steel. This relationship is also true after irradiation and the coarse-grained steel shows a greater radiation induced increase in transition temperature after ~10^{20} n/cm² than the fine-grained steel.

Mogford, Churchman, and Hull[29] have also observed that irradiation produces lesser changes in the impact properties of fine-grained samples of an En2 mild steel than in coarse-grained specimens. The effect of neutron doses up to $1{\cdot}9\times10^{18}$ n/cm² at 50–100°C on the notch-impact properties of medium grain sized (5000 grains/mm²) and ultra-fine grain sized (20000 grains/mm²) specimens were studied. After a dose of 1×10^{18} n/cm² no change was detected in the transition curve of the ultra-fine grain size specimens. For the medium-grain size samples, small doses ($2{\cdot}5\times10^{17}$ and 1×10^{18} n/cm²) caused a considerable reduction in the energy absorbed in the ductile region of the curve and a small increase in transition temperature.

Effect of heat-treatment

The influence of the structure of the steel on the susceptibility to radiation damage has been investigated by Trudeau.[21] A HY–65 steel (0·12%C–0·48%Mn–0·21%Si–2·16%Ni–0·39%Mo–0·11%V–0·70%Cu) was heat-treated as follows:

(i) normalized from 954°C and tempered at 663°C for 1 h
(ii) austenitized at 954°C, austempered at 371° to 427°C and tempered at 663°C for 1 h
(iii) austenitized at 954°C, brine quenched, and tempered at 663°C for 1 h.

TABLE XIV The effects of irradiation on the notched-bar properties of HY–65 steel after various heat-treatments[21]

Condition	Transition temperature, °C Before	After	Change	Max. (ductile) energy, ft lb Before	After	Change
Normalized and tempered	−85	112	+197	7·8	4·6	−3·2
Austempered and tempered	−108	72	+180	7·8	4·4	−3·4
Quenched and tempered	−114	24	+138	7·8	4·0	−3·8

TABLE XV Effect of specimen dimensions on the increases in transition temperature of steels irradiated to 5×10^{18} n/cm² (>1 MeV) at 80°C[5, 16]

Steel	Transition temperature increase,* °C Subsize Izod†	Charpy V-notch‡
ASTM–A212B	25	60
ASTM–A301B	28	60

* Mid-range energy values.
† 0·2-in. square with a notch 0·060 in. deep, an included angle of 45°, and a root radius of 0·005 in.
‡ 10-mm square with a notch 2 mm deep, an included angle of 45°, and a root radius of 0·25 mm.

Substandard notched bars which had been given these respective heat-treatments were irradiated to about 10^{20} n/cm² (>500 eV) at 49° to 68°C. The results of the impact tests are summarized in Table XIV.

Table XIV indicates that a quenched and tempered structure is the most resistant to radiation damage when increases in transition temperatures are considered but the least resistant as far as the energy absorbed values are concerned. The quenched and tempered structure gives the lowest transition temperature in the irradiated and unirradiated conditions. The increases in transition temperatures given in Table XIV are far greater than those reported by other workers for a comparable or even higher irradiation dose. Whether this is a consequence of the low irradiation temperature or the type of steel is not known.

The effects of neutron irradiation on the transition temperatures and ductile energy values of plain carbon and low-alloy ferritic steels are summarized in the Appendix. The values quoted must only be considered approximate as they have been estimated from published graphs. In addition, the results have been obtained in tests using substandard specimens and thus must only be considered relative. Not one of the steels shows complete immunity from radiation damage; the extent of the damage is governed principally by the type of steel and the other factors which have been discussed above.

Effect of specimen dimensions

Tentative results[5, 16] suggest that there may be a size

TABLE XVI Tensile results on irradiated carbon-steel weldment,[5] strain rate 0·05/min, irradiation temperature 95°C (max)

Material	Dose, n/cm² >1 MeV	YS, 10^3lb/in²	UTS, 10^3lb/in²	Total elongation, %	Uniform elongation, %
ASME–SA–212 Base plate (1)	0	41·3	75·4	36	27
	$1{\cdot}7\times10^{19}$	91·6	98·0	11·6	5·8
	10^{20}	108·5	115·8	7	4·0
E–7016 Weld metal(2)	0	57·9	73·2	25·5	15·5
	0	59·0	71·7	24·0	15·0
	0	66·5	74·0	20·5	12·5
	5×10^{18}	69·3	77·5	18·5	10·5
	$1{\cdot}7\times10^{19}$	108·7	*	8·0	0
	$1{\cdot}7\times10^{19}$	106·5	*	8·5	0
	10^{20}	115·0	*	7·5	0

	Analysis, % C	Mn	Si	S	P	
1	0·28–0·33	0·9 (max)	0·15–0·30	...	...	Aluminium killed
2†	0·10–0·14	0·4–0·6	trace	0·04 (max)	0·04 (max)	ref.30

* Load continuously decreased after initial yielding.
† Electrode analysis.

TABLE XVII Sub-standard Izod impact-test results on irradiated carbon-steel weldments[5, 20]

Plate thickness, in.	Welding and heat-treatment		Temp. of Irradiation, °C	Dose, n/cm² >1 MeV	Ductile/brittle transition temp., °C Before	After	Change*	Maximum (ductile) energy, ft lb Before	After	Change
4·5	Welding electrode to specification E.7016†	Parent plate	<95	5×10^{18}	−20	−20 to 40	+19	6·5	5·6	−0·9
				$\sim10^{20}$	−20	95 to 175	+130	6·5	3·3	−3·2
	No subsequent heat-treatment	Weld metal	<95	$1\cdot2\times10^{19}$	−50	20 to 60	+95	12·5	7·5	−5·0
				$1\cdot7\times10^{19}$	−50	65	+115	12·5	7·0	−5·5
				$1\cdot2\times10^{20}$	−50	100 to 130	+170	12·5	5·8	−6·7
		Heat-affected zone	<95	$7\cdot6\times10^{19}$	−75 to +35	130	+170	11·3	3·8	−7·5
2	Welding electrode to specification E.6030†	Parent plate	20–60	8×10^{19}	52 to 71	110 to 141	+65	6·1	4·7	−1·4
		Weld metal	20–60	8×10^{19}	−59 to −40	4 to 24	+65	6·8	7·8	+1·0
	No subsequent heat-treatment	Heat-affected zone	20–60	8×10^{19}	−29 to 41	80 to 121	+95	6·2	5·5	−0·7
2	Welding electrode to specification E.6030†	Parent plate	20–60	8×10^{19}	52 to 71	140 to 166	+95	6·5	>4·5	>2·5
		Weld metal	20–60	8×10^{19}	−15 to 35	30 to 68	+39	7·1	4·6	−2·5
	Weldment stress relieved at 620°C for 6 h	Heat-affected zone	20–60	8×10^{19}	24 to 46	96 to 124	+75	6·8	4·8	−2·0

Steel and electrode analysis, % C	Si	Mn	S	P	Notes
ASTM–A212–B 0·28–0·33	0·15–0·30	0·9 (max)	...	...	Aluminium killed
E.7016 0·10–0·14	trace	0·4–0·6	0·04 (max)	0·04 (max)	Low-hydrogen potassium coating
E.6030 0·10–0·14	...	...	...	...	High iron oxide type of coating, with sodium silicate binder

* Mid-range energy values. † Electrodes.[30]

effect in irradiated steels. The shifts in transition temperature for Charpy V-notch specimens were at least a factor of 2 greater than for subsize Izod specimens of the same steels, as shown in Table XV.

Welded steel structures

Since steel plates for pressure vessels are welded during construction, effort has been devoted to the study of neutron-irradiation effects on the tensile and impact properties of specimens machined from carbon-steel weldments.

Tensile test results[5] for a 4·5-in. thick carbon-steel weld plate are given in Table XVI. The specimens were machined from the plate with their longitudinal axes perpendicular to the weld and parallel to the plate surface, and were given no subsequent heat-treatment.

In this radiation-sensitive steel, high dosage reduced the work-hardening capabilities to low values, and about 5% or less uniform elongation precedes necking. The weld metal appears to be even more radiation sensitive than the parent plate, no uniform elongation preceding necking after the high doses.

Impact-test results before and after irradiation on several carbon-steel weldments are summarized in Table XVII. The impact specimens were machined with their longitudinal axes perpendicular to the weld and parallel to the plate surface and notched in a face perpendicular to the plate surface.

The changes in impact properties of the 4·5-in. thick plate after irradiation are far greater than those of the 2-in. thick plates after comparable neutron doses. This may be a consequence of the thickness of the plate, a difference in grain size or a difference in temperature of irradiation.

The impact properties of the deposited welds and heat-affected zones are superior to those of the base plate before irradiation. Both the irradiated weld metal and heat-affected zones of the 4·5-in. thick plate show greater changes in impact behaviour than the base plate but the impact characteristics of the weld metal still appear to be better than those of either the base plate or heat-affected zones at the highest neutron doses.

Stress relieving after welding has a beneficial effect in reducing the increases in transition temperatures of

TABLE XVIII Effects of neutron irradiation on the transition temperatures of welded steel plates[26, 27]

		Ductile/brittle transition temperature, °C (50% fibrous fracture) Unirradiated	Irradiated at 50–60°C $2\cdot7\times10^{19}$ n/cm²	50–60°C $8\cdot5\times10^{19}$ n/cm²	130–140°C $2\cdot7\times10^{19}$ n/cm²	130–140°C $8\cdot5\times10^{19}$ n/cm²
Mild steel	Parent plate	−75	−42	0	−28	+29
	Weld metal	−42	−7		+2	
	Heat-affected zones	−60	−10	+35	−1	+40
			4×10^{19} n/cm²	$7\cdot6\times10^{19}$ n/cm²	4×10^{19} n/cm²	$7\cdot6\times10^{19}$ n/cm²
Low-alloy steel	Parent plate	3	38	76	69	77
	Weld metal	−18	58	100	75	105

Analysis, %	C	Si	Mn	Ni	Cr	Mo	V	Notes
Mild steel								
Parent plate composition	0·14	0·11	1·07	...	...	...	...	Aluminium killed
Weld metal analysis	0·05	0·14	0·47	0·11	...	...	...	2-in. plate normalized from 920°C and the welded portion stress relieved at 630°C for 4½ h
Low-alloy steel								
Parent plate composition	0·155	0·18	1·24	...	0·49	0·28	0·07	
Weld metal analysis	0·12	0·34	0·72	...	0·16	0·21	0·03	4½-in. thick plate normalized from 950°C, welded and machined specimens stress relieved at 675°C

TABLE XIX Neutron irradiation effects on the fatigue properties of an ASTM–A212 steel[31]

Fatigue limit for 10^7 cycles, lb/in²				Notch effect, Kf*	
Unirradiated		Irradiated		Unirradi-	Irradiated
Unnotched	Notched	Unnotched	Notched	ated	
48000	28000	42000	35000	1·7	1·2

* $Kf = \frac{\text{fatigue limit unnotched}}{\text{fatigue limit notched}}$

the weld metal and heat-affected zones but causes a greater reduction in the maximum (ductile) energy values. However, the transition temperatures and ductile energies are higher and lower respectively after irradiation in the stress-relieved plate than in the plate tested in the as welded-condition.

Neutron-irradiation effects on the notched-bar properties of welded-steel plates have also been reported by Burnett *et al.*[26] and Harries and Judge.[27] Single-notch Izod-type specimens were machined from the parent plate, weld metal, and heat-affected zones of a mild steel and a low-alloy steel and tested in slow bend. The transition-temperature results are summarized in Table XVIII.

The increases in transition temperature are of the same order of magnitude as those given in Table XVII. However, the neutron doses quoted in Table XVIII are much lower since they are based on measurements of thermal flux in positions where the ratio of thermal neutrons to neutrons with energies > 1 MeV is about 8 to 1.

Fatigue properties

Plane bending fatigue test results on unirradiated and irradiated (10^{19} n/cm² (> 1 MeV) at 20–60°C), notched and unnotched specimens of a normalized boiler-plate steel have been reported by Leeser[31] and the results are given in Table XIX.

Irradiation lowers the fatigue limit of the unnotched specimens and raises that of the notched specimens. The stress concentration of the notch is less effective after irradiation and the fatigue curve of the notched specimens approaches that of the unnotched specimens. However, no mention was made by Leeser of the effect of irradiation on the fatigue life at high stresses.

Weldability

The re-welding of irradiated pressure-vessel steels has been considered by Hutchinson.[32] Weldability tests were made on unirradiated and irradiated, 2-in. thick plates of an ASTM–A212–B steel. Irradiation to an integrated thermal flux of 10^{16} n/cm² at 50°C (max) had no effect on the weldability and had no adverse effects on the RT mechanical properties of the base plate and weld joints. No correlation between welding defects and prior irradiation and no peculiar effects or transformations were observed. The only factor which might have influenced the quality of the weld in the irradiated material was the encumbrance of the welder with additional clothing and safety precautions against the radiation hazard.

AUSTENITIC STEELS

Hardness

The effects of neutron irradiation on the hardness of unstabilized and stabilized austenitic stainless steels were first reported by Billington and Siegel.[33] The steels were exposed to reactor irradiation in the form of discs in the 'as-received' condition and after quenching from about 1090°C. The steels were hardened only very slightly by exposure to $1{\cdot}7\times10^{18}$ n/cm², the increases ranging from 1 to 3 numbers on the Rockwell B scale for the 'as-received' and quenched materials. A dose of 5×10^{19} n/cm² hardened the samples appreciably and the increases ranged from 9 to 15 Rockwell B numbers. Extending the irradiation to $8{\cdot}1\times10^{19}$ n/cm² caused a further hardening of only one number. Such a slight increase in hardness for a 60% increase in exposure suggests the possibility of a rapid approach to saturation by neutron bombardment.

However, Bruch and McHugh[6] and Bartz[34] have not observed a saturation of the hardness increases in type 347 austenitic stainless steel when irradiated to doses of up to 10^{20} n/cm² (> 1 MeV) at 80°C and $3{\cdot}76\times10^{22}$ n/cm² (> 100 eV) at 40°C respectively.

The results of Sutton and Leeser[8] in Table XX confirm that radiation-induced hardness increases are greater for fully annealed metals than those initially hardened. In addition, greater hardness changes are obtained after irradiation at RT than at elevated temperatures.

Tensile properties

Radiation-induced changes in the tensile properties of annealed austenitic stainless steels reported by Wilson and Berggren[12] are given in Table XXI. Konobeevsky *et al.*[35] obtained substantially similar results for steels irradiated at 80°C to integrated doses of $1\text{–}3\times10^{20}$ n/cm² (energies not specified).

Bruch and McHugh[6] have observed that the yield and ultimate tensile stresses of an annealed type 347 stainless steel increased continuously with increasing neutron dose at 80°C. At the maximum exposure

TABLE XX Change in hardness of austenitic stainless steels after irradiation*

Steel	Specified composition	Condition	Integrated neutron flux, 10^{19} n/cm² Thermal	>1 MeV	Irradiation temp., °C	Brinell hardness* Before irradiation	After irradiation
304	0·08%C (max); 18–20%Cr; 8–11%Ni; 2%Mn (max)	Annealed	1·2		205–260†	131	131
		Nitrided	37	51	21–26	654	810
309	0·20%C (max); 22–24%Cr; 12–15%Ni; 2%Mn (max)	Annealed	1·2		205–260†	152	158
316	0·10%C (max); 16–18%Cr; 10–14%Ni; 2–3%Mo	Annealed	37	51	21–26	154	228
		Annealed	1·2		205–260†	143	143
		Cold worked	37	51	21–26	226	285
347	0·08%C (max); 17–19%Cr; 9–12%Ni; Nb10× %C	Annealed	3		280†	183	183
		Nitrided	1			656	656
		Annealed	1·2		205–260†	152	152

* Converted from Rockwell hardness scales. † Irradiated in flowing water.

TABLE XXI Tensile properties at room temperature of annealed and irradiated austenitic stainless steels[12]

Steel	Specified composition	ASTM grain size	Control or irradiated†	YS (0·2% P.S.) 10^3 lb/in²	UTS, 10^3 lb/in²	Uniform elongation, %	Reduction in area, %
301	0·08–0·20%C; 16–18%Cr; 6–8%Ni; 2%Mn (max)	2	Control	38·4	98·7	56	83
			irradiated	87·0	113·2	48	81
302	0·08–0·20%C; 17–19%Cr; 8–10%Ni; 2%Mn (max)	4	Control	33·8	95·5		
			irradiated	84·0	111·3		
302B	0·08–0·20%C; 17–19%Cr; 8–10%Ni; 2%Mn (max); 2–3%Si	4	Control	33·5	107·8		
			irradiated	81·5	125·0		
304 ELC	0·03%C; 18–20%Cr; 8–12%Ni; 2%Mn (max)	4	Control	24·3	86·3	63	74
			irradiated	75·5	103·8	58	73
321	0·08%C; 17–19%Cr; 8–11%Ni; 2%Mn (max); Ti 5× %C	7	Control	31·2	84·8		
			irradiated	90·6	105·8		
347	0·08%C; 17–19%Cr; 9–12%Ni; 2%Mn (max); Nb 10× %C	8	Control	37·0	97·6	49	71
			irradiated	96·5	114·8	25	62

† All the irradiated specimens received an integrated flux of $3·9\times10^{19}$ n/cm² (>1 MeV) at 95°C (maximum) with the exception of types 304 ELC and 321 which received $7·8\times10^{19}$ n/cm² (>1 MeV).

[$1·2\times10^{20}$ n/cm² (>1 MeV)], the yield stress increased from the unirradiated value of 49000 lb/in² to about 113000 lb/in². There was an accompanying small decrease in ductility although the material was quite ductile even after $1·2\times10^{20}$ n/cm². However, in samples of this steel which had initially been cold swaged to reductions in area of 7, 17, 37, and 58%, the changes in strength and ductility reached saturation values in the range $0·5–1\times10^{19}$ n/cm². At higher exposures there were no further changes and all the samples were ductile.

No evidence of saturation effects was found in type 347 austenitic steel (condition unspecified) irradiated for six years in the MTR reactor at about 40°C.[34] The results of tensile tests at RT after such long exposures are given in Table XXII.

The ratio of thermal flux to flux >100 eV was about unity in the irradiation position used, but no attempt was made to distinguish between the effects of fast neutrons and their disturbance of the original crystal lattice and the effects of thermal neutrons and the gradual addition of impurity atoms to the metal.

Sutton and Leeser[8] found only minor increases in yield and ultimate tensile stresses of several annealed austenitic stainless steels irradiated to 10^{19} n/cm² (thermal) at 205° to 260°C. Murphy and Paine[36] have irradiated tensile specimens of annealed type 347 stainless steel at temperatures in the range 228°–316°C to a maximum integrated flux of $4·3\times10^{20}$ n/cm² (fast). In the range 240°–290°C the tensile strength increases as a straight-line function of the integrated flux. However, at the highest irradiation temperature, annealing of the damage occurs simultaneously with irradiation, the healing effect becoming more vigorous with increasing total flux dose.

Austenitic stainless steels acquire a yield point in tensile tests after irradiation if the strain rate is sufficiently high.[12, 6] The stress/strain curves for an annealed type 347 austenitic steel before and after irradiation are shown in Fig.4.

Curve A is a composite curve from two tests on unirradiated metal at strain rates of 0·01 and 0·05/min. Changing the strain rate by a factor of five does not change the curve by any measurable amount. Curve B is for the irradiated steel pulled at a rate of 0·01/min. The curve is markedly different from that of the unirradiated steel and the rate of work hardening is very small. Curve C is for the irradiated steel pulled at a rate of 0·05/min; this curve, shown in detail in the inset, goes through a maximum at an elongation of 0·7%, falls and then rises to the maximum load. Of the steels given in Table XXI, only the types 304 ELC and 347 stainless steels showed these yield points at a strain rate of 0·05/min. The remainder exhibited the type of stress/strain curve shown by curve B in Fig.4.

The appearance of a yield point is a function of both strain rate and integrated neutron dose.[12] For example type 304 ELC stainless steel irradiated at 7×10^{18} n/cm² (>1 MeV) at 95°C (max) and tested in tension over the range 0·05–2/min showed a yield point only at the highest strain rate. However, the yield stress of the irradiated steel was strongly dependent on strain rate over this range and increased with increasing strain rate. The unirradiated specimens showed no unusual behaviour or strong strain-rate dependence.

Impact properties

These steels do not show a ductile/brittle transition temperature in the unirradiated or irradiated conditions but a gradually sloping curve covering all ductile fractures. Subsize Izod impact specimens of unirradiated and irradiated [$>10^{19}$ n/cm² (>1 MeV)] austenitic stainless steels were tested at −200°C by Wilson and Berggren.[12] All the unirradiated specimens bent but no cracks were initiated at the root of the notch. All the irradiated specimens cracked in the same test and the fractures propagated at least halfway across the specimen but complete fractures did not occur.

Leeser[31] has reported the results of Charpy tests on V-notch specimens at temperatures in the range −185° to 150°C before and after irradiation to integrated doses of 6×10^{18} n/cm² (>1 MeV) in circulating water at 280°C and to $3·5\times10^{19}$ n/cm² (>1 MeV) at 20°–60°C. The absorbed-energy data indicated that the unexposed specimens were more ductile with decreasing ductility in the following order:

Specimens unirradiated but exposed to water at 280°C
Specimens irradiated in water at 280°C
Specimens irradiated dry at 20°–60°C

Creep

Wilson and Billington[37] have reported that austenitic stainless steel shows a decreased creep rate at 650°C under irradiation but at the same stress at 815°C there was a slight increase in creep rate. Faris[38] has summarized the data from in-pile creep experiments on structural materials in the USA. Type 347 austenitic

TABLE XXII Effects of high neutron doses on the room temperature tensile properties of type 347 austenitic stainless steel[34]

Dose, n/cm² >100 eV	0·2% PS, lb/in²	UTS, lb/in²	Elongation, %	R. in A. %
0	61600	95800	63·2	78·0
$2·4 \times 10^{21}$	98000	109000	51·6	78·5
$7·2 \times 10^{21}$	97300	109700	50·6	77·8
$2·6 \times 10^{22}$	100800	107250	44·0	65·0
$3·76 \times 10^{22}$	106930	115310	32·0	74·0

stainless steel shows a slight increase in creep rate at temperatures above 760°C and a decrease below this temperature. This may be connected with the fact that the hardness of this steel measured after irradiation was increased by irradiation only at temperatures below 760°C.

Fatigue properties

Irradiation to 10^{19} n/cm² (fast) at 20°–60°C had little effect on the behaviour of type 304 steel [0·08%C (max); 18–20%Cr; 8–11%Ni; 2%Mn (max)] in either notched or unnotched conditions.[31]

Magnetic susceptibility

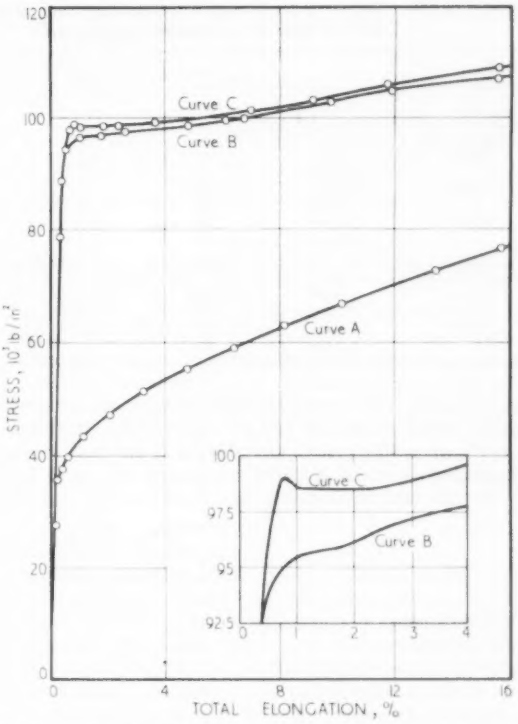
Transformation of austenite to ferrite by neutron irradiation in type 347 stainless steel (0·041%C; 1·49%Mn; 20·5%Cr; 10·9%Ni; 0·52%Nb) in the annealed and cold-rolled condition has been studied by Reynolds *et al.*[39] by measuring the ferromagnetic saturation induction. This alloy above about 357°C has a face-centred-cubic structure but below this temperature the stable state is a mixture of face-centred-cubic austenite and body-centred-cubic ferrite. The estimated volume percentages of ferrite in the annealed and 50% cold-worked samples were 0·02 and 0·19 respectively. The ferrite content of the annealed material increased by 0·002% by volume and that of the 50% cold-worked material by 0·057% by volume after neutron irradiation to the maximum dose given. The change in ferrite content increased with increased initial ferrite content and with increasing irradiation. The authors believed that the fractional increase in ferrite content was much too small to cause any significant change in density. Chang[40] has interpreted this type of irreversible change on the basis of the temperature distribution in the immediate neighbourhood of a thermal spike.

An increase in the magnetic susceptibility of stainless steels after irradiation to 10^{19} n/cm² (thermal) has also been observed by Sutton and Leeser.[8] However, it was concluded that the amount of austenite transformed to ferrite was not sufficiently large to affect the corrosion resistance of the steels.

ANNEALING OF RADIATION DAMAGE

The annealing characteristics of radiation damage in pure-iron single crystals have been studied by Kunz and Holden[4] by comparing the yield strengths of partly recovered crystals with those of crystals in both the unirradiated and irradiated conditions. The crystals were irradiated to 10^{18} n/cm² (total) at 50°C (max) and annealed for times ranging from 1 to 10^4 min. Annealing of the radiation damage occurred in the range 225°–300°C with an activation energy of 3·1 eV, the activation energy for self-diffusion in iron.

Meyer[41] observed that radiation damage in a mild



4 *Conventional tension stress/strain curves for annealed austenitic stainless steel type 347, after Berggren and Wilson[5]*
Curve A: Composite curves from two tests on unirradiated metal at strain rates of 0·01 and 0·05 in./in./min
Curve B: Irradiated ($7·8 \times 10^{19}$ nvt), strain rate 0·01 in./in./min
Curve C: Irradiated ($7·8 \times 10^{19}$ nvt), strain rate 0·05 in./in./min

steel (0·19%C; 0·72%Mn; 0·006%Si; 0·004%Al) induced by deuteron bombardment annealed out at temperatures between 260° and 480°C. At 260°C very little recovery of transition temperature occurred. However, at 315°C the transition temperature was lowered from 18° to 8·8°C while at 480°C it had returned to the unirradiated value (−1·1°C). It was also observed that 5% strain hardening increased the transition temperature of the unirradiated specimens from −1·1°C to +9·5°C and that recovery occurred after annealing for 1½ h at temperatures between 315° and 371°C. Because of the differences in the recovery temperatures, the author concluded that the annealing processes for radiation damage and cold work were different.

Bleiberg[9] found that the hardness and impact properties of an ASTM–A212–B steel (0·29%C; 0·75%Mn; 0·16%Si; 0·003%Al) irradiated to about 10^{20} n/cm² (>1 MeV) at 100°C (max) started to recover after 1 h at 350°C and was complete after 1 h at 425°C. However, these two properties did not anneal out at the same rate at intermediate temperatures. Konobeevsky *et al.*[35] have also found that the major portion of the radiation-induced hardness increases in Armco iron irradiated to 10^{20} n/cm² at 250°–300°C were recovered in the temperature range 300°–400°C (time of annealing not specified).

Trudeau[21] investigated the effect of post-irradiation

TABLE XXIII Recovery from irradiation damage and cold work in type 347 austenitic stainless steel[36]

Condition		Rockwell hardness B scale
Annealed		75
Irradiated to $1{\cdot}2\times10^{20}$ n/cm² (fast)		98
Annealed after irradiation:		
200°C	1 day	97
	8 days	97
400°C	1 day	94
	8 days	86
600°C	1 day	79
	8 days	79
Cold worked 10%		100
Annealed after cold work:		
400°C	1 day	98
	11 days	98
600°C	1 day	94
	8 days	93

annealing on the transition temperature curves of an ASTM–A201 steel (0·17%C; 0·57%Mn; 0·21%Si; 0·041%Al; 0·004%Al_2O_3) irradiated at 49°–68°C to an integrated dose of 6×10^{19} n/cm² (>500 eV). The results are summarized below:

	Ductile–brittle transition temp., °C	Max (ductile) energy ft/lb
Unirradiated	−60	7·5
Irradiated	38	6·4
Irradiated and annealed at 260°C for 6 h	52	5·6
Irradiated and annealed at 335°C for 6 h	−12	7·8

Irradiation followed by the annealing at 260°C has caused the transition temperature to be increased further and the maximum absorbed energy to be lowered. This annealing temperature is within the so-called 'blue-brittle' range and it is not known whether the further detrimental changes in properties are due to enhanced dislocation locking by the carbon and nitrogen atoms or to the migration of the point defects introduced during irradiation to sites of lower energy where they are more effective in hindering the movement of dislocations. Annealing at 335°C for 6 h has resulted in partial recovery of the transition temperature and the maximum energy-absorbed value has been raised to a higher value than that for the unirradiated metal. Baldwin[10, 11] found that annealing at 260°C for up to 100 h produced very little recovery of radiation damage whereas 1 h at 315°C produced almost complete recovery in a plain carbon steel irradiated to $4{\cdot}3\times10^{20}$ n/cm² (>1 MeV) at 1 0°–225°C.

Radiation damage in austenitic stainless steels anneals out at higher temperatures than in plain carbon steels. The results of Murphy and Paine[36] are given in Table XXIII.

The radiation damage begins to anneal out between 200° and 400°C and annealing at 600°C results in almost complete removal of the radiation-induced hardness increase. Comparison with the annealing temperatures for the cold-worked specimens suggests that different annealing mechanisms are involved, in agreement with Meyer's[41] observations.

The differences in the temperatures at which post-irradiation annealing of radiation damage occurs suggest that recovery may be a function of irradiation temperature, integrated neutron dose, flux intensity, the type of steel, or a combination of these factors.

TABLE XXIV Effect of irradiation and annealing on the yield stress of high-purity iron[6]

Condition	YS, lb/in²
Unirradiated	15900
Irradiated 27·7 days at 80°C	22100
Irradiated 27·7 days at 80°C and annealed 14 days at 300°C	18200
Irradiated 27·7 days at 300°C	20600

Several investigators[5, 8, 12, 14] have established that irradiation at temperatures in the range 300°–370°C produces lesser changes in hardness, tensile, and impact properties than irradiation at lower temperatures. However, Bruch and McHugh[6] have shown that in materials in which radiation damage can be removed by high-temperature annealing after irradiation, the damage is not so completely removed when the annealing and irradiation take place simultaneously. Their results on high purity iron are summarized in Table XXIV.

A larger change in yield stress is produced by irradiation at 300°C than by annealing at 300°C after irradiation at 80°C.

Since annealing occurs as a function of both time and temperature, it is anticipated that the change in properties after irradiation at temperatures of 300°C and above will be dependent on the neutron-flux intensity. The greater the rate at which the damage is produced, the greater the amount of damage that will persist after irradiation at these temperatures.

MECHANISM OF RADIATION EMBRITTLEMENT

The effects of neutron irradiation at 50°–100°C on the lower yield stresses σ_y and fracture stresses σ_f at RT, −78°C and −196°C of specimens of an En2 steel with grain sizes in the range 310–2840 grains/mm² have been studied by Churchman *et al.*[17, 24]

The values of σ_y and σ_f were used in the following equations derived by Hall[42] and Petch[43, 44] relating the variation of σ_y and σ_f with the grain diameter l:

$$\sigma_y=\sigma_i+k/\sqrt{l} \quad \ldots\ldots(2)$$

$$\sigma_f=\sigma_i+k^*/\sqrt{l} \quad \ldots\ldots(3)$$

where k measures the tensile stress needed to start plastic yielding in the grains ahead of the plastic front and is sensitive to temperature and rate of straining; k^* measures the tensile stress needed to crack the metal at the tip of a slip band and is almost independent of temperature and rate of straining; σ_i measures the friction resistance to the movement of free dislocations in the lattice.

Values of σ_y and σ_f at RT, −78°C and −196°C are given in Table XXV for two grain sizes. Irradiation increases the yield stress and fracture stress at all temperatures and the increase in yield stress is roughly proportional to the cube root of the neutron dose.

σ_i, ky (which is a measure of the dislocation locking stress and is equal to $k/2\sqrt{2}$) and k^* were obtained from a plot of σ_y and σ_f against $1/\sqrt{l}$. K and hence ky, remains sensibly constant with irradiation and the respective values of ky at the three testing temperatures are as follows:

20°C $ky=2{\cdot}89\times10^7$ cgs units
−78°C $ky=3{\cdot}70\times10^7$ cgs units
−196°C $ky=4{\cdot}64\times10^7$ cgs units

TABLE XXV Effects of neutron irradiation on the lower yield and fracture stresses of En2 steel[24]

Integrated neutron dose n/cm²	σ_y, lb/in² 20°C Coarse*	Fine†	−78°C Coarse	Fine	−196°C Coarse	Fine	σ_f, lb/in² 20°C Coarse	Fine	−78°C Coarse	Fine	−196°C Coarse	Fine
0	32000	38000	46100	52500	101000	115600	83000	130000	109500	145000	115500	170000
1×10^{18}	36100	43800	57000‡	63200‡	117500	122000	81000	121000	120000‡	129000‡	117500	188500
$1{\cdot}5\times10^{19}$	45700	54000	76600‖	77900‖	Fractured	141600	91500	127000	104000‖	126000‖	132000	155000
9×10^{19}	71400	82600	87800	100000	Fractured	Fractured	93000	139000	102000	144500	108000	151000

* Coarse-grain size. 530 grains/mm². † Fine-grain size. 2135 grains/mm². ‡ Integrated neutron dose $=2\times10^{18}$/cm².
‖ Integrated neutron dose $=1{\cdot}75\times10^{19}$/cm².

These results give a linear variation of ky with temperature, $\delta ky/\delta T=8{\cdot}0\times10^4$ cgs units.

The cohesive strength of the lattice was also unaffected by the irradiation but σ_i increases with the total neutron dose and the values are summarized in Table XXVI.

The increase of σ_i suggests that irradiation produces dispersed islands of damage, such as clusters of point defects, that are sufficiently mobile to withstand thermally activated movements of dislocations. The constancy of the ky term indicates that irradiation has only a small effect on the dislocation locking. In the En2 steel the dislocations are strongly locked by segregated carbon and nitrogen atoms and thus additional locking by the point defects might not be expected. However, in certain alloy steels where the dislocations are not strongly locked by carbon and nitrogen atoms, an increase in the ky as well as the σ_i terms may be obtained provided that the point defects are mobile at the irradiation temperature.

Irradiation, by increasing σ_i, increases the transition temperature in agreement with the following theoretical relation for the transition from ductile to brittle fracture derived by Cottrell[23]:

$$(\sigma_i/\sqrt{d}+ky)ky=\beta\gamma\mu \quad \ldots\ldots(4)$$

where $\sigma_y=\sigma_i+ky/\sqrt{d}$.

These equations refer to shear stresses and d is half the grain diameter whereas in equations (2) and (3) tensile stresses are used and l is the grain diameter. To a first approximation the shear stress is half the tensile stress.

β depends on stress distribution, being unity for uniaxial tension and $\frac{1}{3}$ at the root of a plastic notch in hydro-static tension.

γ is the effective surface energy for propagation of cracks.

μ is the shear modulus.

The term $\sigma_i/\sqrt{d}$ in equation (4) shows that the critical grain size for ductility decreases as σ_i increases and that fine-grained materials can withstand greater hardening by increasing σ_i than the coarse grained specimens without becoming brittle.

TABLE XXVI Variation of σ_i with integrated neutron dose[24]

Test temperature, °C	Integrated neutron dose, n/cm² × 10¹⁸	σ_i lb/in²
20	0	6500
	1	8000
	15	15000
	57	20500
	90	26500
−78	0	11500
	2	16000
	18	23500
	91	33000
−196	0	38500
	1	45500
	15	52000

Churchman, Hull, and Mogford[24] have shown in tests at −196°C that the product of σ_i and $\sqrt{d}$ is independent of dose. At −196°C the transition grain size is 231 grains/mm² for unirradiated specimens and this is increased to 2800 grains/mm² after a dose of 9×10^{19} n/cm². The results quoted earlier are in agreement with Cottrell's prediction that fine-grained steels have a greater resistance to radiation embrittlement than coarse-grained steels.

CONCLUSIONS

Irradiation of steels with fast neutrons causes the displacement of atoms from their equilibrium lattice positions resulting in the formation of vacant lattice sites and interstitial atoms. In a mild steel irradiated at 50°–100°C the point defects remain as clusters in the lattice and increase the frictional assistance to the movement of dislocations, the dislocation locking stress being unaffected.

Most of the experimental studies to date have been concerned with the neutron-induced changes in the hardness, tensile, and notched-bar properties of steels and little or no attention has been given to the effect of neutron irradiation on the creep and fatigue properties.

The primary effects of fast neutron irradiation on ferritic steels are to increase the yield and, to a lesser extent, the ultimate tensile strengths and to reduce the elongation and reduction in area values in tensile tests; to raise the ductile/brittle transition temperatures and lower the ductile energy values in notched-bar tests; and to increase the hardness. The extent of the changes in these properties is dependent on irradiation variables such as the integrated-neutron dose and temperature of irradiation. Preliminary results have shown that the increases in transition temperatures of a mild steel irradiated at 50°–100°C are roughly proportional to the cube roots of the integrated neutron doses. Irradiation at temperatures in the range 260°C to about 350°C produces lesser changes in tensile and notched-bar properties than irradiation at lower temperatures. This is due to the greater mobility of the point defects at the higher temperatures and their consequent annihilation either at grain boundaries or by mutual annihilation of the vacancies and interstitials. However, in some ferritic steels, principally low-alloy steels, the changes in properties are also affected by the irradiation temperature in the range 50° to 130°C, a greater amount of damage being produced at the higher temperature. This effect is thought to be due to the point defects migrating to positions where they are more effective in preventing the movement of dislocations at the higher temperatures. Preliminary work aimed at clarifying

APPENDIX Effects of neutron irradiation on the impact properties (substandard specimens) of ferritic steels

Item	Steel	Composition	Plate thickness or rod diameter	Heat-treatment	ASTM Grain size	Temp. of irradiation, °C	Integrated neutron flux, n/cm²	Neutron energy	Ductile/brittle transition temperature,* °C			Maximum (ductile) energy, in. lb			Reference
									Before	After	Change	Before	After	Change	
1	ASME SA–70	0·25–0·30%C; 0·8%Mn (max); 0·04%S (max); 0·04%P (max)	0·25-in. dia. rod	None	3–4	50	$7·5\times10^{19}$	Slow	−30	+40	+70	88	>52	<−36	8, 20
2	ASME SA–70	0·25–0·30%C; 0·8%Mn (max); 0·04%S (max); 0·04%P (max)		Not stated		50	$2·5\times10^{19}$	>1 MeV	−30	50	+80				38
3	ASTM A–70	0·21%C; 0·4%Mn; 0·04%S (max); 0·04%P (max)		Unknown		<95	$7·5\times10^{19}$	Total	−23	38	+61	80	45	−35	25
4	ASTM A212B	0·24%C; 0·81%Mn; 0·248%Si; 0·04%S; 0·02%P		Normalized from 1040°C	5	<90	10^{19}	>1 MeV	−5	0	+5	80	80	0	12
						<90	10^{20}	>1 MeV	−5	50	+55	80	50	−30	
5	ASTM A212B	0·20)C; 0·82%Mn; 0·22%Si; 0·03%S; 0·018%P	¾-in. thick plate	Hot rolled	7	<95	5×10^{18}	>1 MeV	−60	−40	+20	52	40	−12	5
						<95	$\sim10^{20}$	>1 MeV	−60	+70	+130	52	22	−30	
6	ASTM A242	0·07%C; 0·15%Mn; 0·07%Si; 0·048%Al; 0·39%Cu; 0·42%Ti; 0·011%P; 0·029%S		Normalized from 930°C		<95	10^{19}	>1 MeV	−40	−3	+37	120	110	−10	25
7	ASTM A285A	0·11%C; 0·36%Mn; 0·020%S; 0·018%P	¾-in. thick plate	Hot rolled	7	<95	5×10^{18}	>1 MeV	−1	+16	+17	83	70	−13	5
8	ASTM A301B	0·11%C; 0·36%Mn; 0·22%Si; 0·98%Cr; 0·47%Mo; 0·026%S; 0·020%P	¾-in. thick plate	Normalized from 930°C	5	<95	5×10^{18}	>1 MeV	−24	+4	+28	75	60	−15	5
9	ASTM 446	0·35%C (max); 1·5%Mn; 1%Si (max); 23–27%Cr; 0·04%S; (max) 0·04%P (max)		Mill annealed		<95	10^{20}	>1 MeV	no transition	188		130	40	−90	25
10		0·173%C; 0·76%Mn; 0·12%P; 0·193%S; 0·01%Al		Normalized	8	<95	2×10^{18}	>1 MeV	−13	48	+61	160	50	−110	25
11		0·167%C; 0·68%Mn; 0·208%S; 0·12%P; 0·04%Al		Normalized		<95	$8·3\times10^{17}$	>0·1 MeV	38	76	+38	100	75	−25	25
						<95	$3·0\times10^{18}$	>0·1 MeV	38	90	+52	100	60	−40	
12	AISI–C1013	0·11–0·16%C; 0·5–0·8%Mn; 0·04%P (max); 0·05%S (max)		Hot rolled	6–7	<95	10^{19}	>1 MeV	−38	−18	+20	115	70	−45	25
13	AISI–C1045			Hot rolled	5	95	$\sim10^{19}$	>1 MeV	+33	+23	−10	55	50	−5	25
14	AISI–C1065	0·14%C; 0·31%Mn; 0·16%Si; 0·022 %S; 0·005%P; 0·05,%Al		Hot rolled	5	<95	$\sim10^{19}$	>1 MeV	−20	+7	+27	110	110	0	25
15	Carilloy T–1	0·1–0·2%C; 0·6–1·0%Mn; 0·15–0·35%Si; 0·7–1·0%Ni; 0·4–0·8%Cr; 0·4–0·6%Mo; 0·03–0·10%Va; 0·15–0·50%Cu; 0·002–0·006%B	½-in. thick plate	Quenched and tempered		<95	5×10^{18}	>1 MeV	−135	−27	+108	50	40	−10	5
						<95	5×10^{19}	>1 MeV	−135	95	+230	50	24	−26	
16	SAE4340	0·38–0·43%; 0·6–0·8%Mn; 0·20–0·35%Si; 1·65–2·0%Ni; 0·7–0·9%Cr; 0·2–0·3%Mo	from 870°C	Quenched Tempered at 205°C		<95	10^{20}	Total	28	101	+73	>200	73	>127	25
				Quenched from 870°C Annealed at 900°C		<95	10^{20}	Total	95	no transition		>150	25	>125	25
17	Tool	1%C; 1·2%Mn; 0·35%Si; 0·5%Cr; 0·5%V		Quenched from 870°C Tempered at 425°C		<95	10^{20}	Total	no transition between 300° and −185°C			12	10	−2	25
				Quenched from 870°C Drawn at 650°C		<95	10^{20}	Total	78	78	0	35	33	−2	25
				Quenched from 870°C Annealed at 900°C		<95	10^{20}	Total	no transition			13	11	−2	25
18	Timken 17–22A	0·3%C; 1%Cr; 0·5%Mo; 0·3%Va		955°C for 1 h 595°C for 6 h Air cooled		<95	2×10^{19}	>1 MeV	no transition			50	40	−10	25

* Mid range energy values.

the influence of the metallurgical structure of ferritic steels on the resistance to radiation embrittlement has shown that the ferrite grain size is the most important variable. Fine-grained steels are more resistant to radiation damage, as measured by the changes in tensile and notched-bar properties, than coarse-grained steels. Therefore, grain-size control appears to be one suitable approach of controlling the extent of radiation damage in steels.

Austenitic steels are generally not prone to radiation embrittlement and in particular do not show a ductile/brittle transition range even after high fast-neutron doses. Although the hardness, yield, and ultimate tensile strengths are increased by neutron irradiation, the reduction in ductility in tensile tests is not as marked as in ferritic steels. Even after integrated neutron doses of about $10^{22}/cm^2$ the austenitic steels retain appreciable ductility.

Post-irradiation annealing of steels irradiated at low temperatures enables the property changes to be recovered. The damage in iron and ferritic steels anneals after about 1 h at temperatures in the range 225°–425°C. The diversity in the actual temperature values at which the damage is recovered suggests that the annealing kinetics may well be a function of the type of steel, integrated neutron dose, temperature of irradiation, or a combination of these factors. The radiation damage in austenitic steels anneals at higher temperatures than in ferritic steels, 1–8 days at 600°C being required to anneal the radiation-induced hardness increases in austenitic steels. The limited evidence available indicates that irradiation at a low temperature followed by annealing at a higher temperature is not equivalent to irradiation at the higher temperature. Comparison of the annealing temperatures for cold-worked and irradiated steels suggests that different annealing mechanisms are involved.

Since ferritic and austenitic steels are used as structural materials in nuclear reactors, the effects of neutron irradiation on the properties are of both technological and academic interest. Although the amount of work already carried out on the effects of neutron irradiation on the properties of steels appears voluminous, knowledge of the phenomenon of radiation damage is still relatively elementary. The most important topics which necessitate additional study to further our understanding of the problem are as follows:

(1) The effects of a wide range of integrated neutron doses on the properties of ferritic and austenitic steels at temperatures up to 700°C.

(2) The influence of various parts of the neutron flux spectrum in reactors on the mechanical properties.

(3) The annealing kinetics of radiation damage in steels as a function of the type of steel, temperature of irradiation, and integrated neutron dose.

(4) The effects of neutron irradiation on the in-pile creep, creep-rupture, and fatigue properties of ferritic and austenitic steels.

(5) Further studies of the influence of grain size in controlling the extent of radiation damage in different types and qualities of mild and low-alloy steels coupled with determinations of the effects of other metallurgical factors such as the size, distribution, and type of carbide and nitride particles.

(6) The effects of neutron irradiation on the ageing characteristics and microstructure of steels. The microstructure of steels may be modified by transfer of atoms across an interface by fast neutron collisions and also by the occurrence of thermal spikes.

(7) The effects of irradiation on the fracture behaviour of large specimens and correlation with results obtained on small specimens to establish whether or not a size effect exists in irradiation.

(8) The mechanism of radiation embrittlement as a function of both the type of steel and temperature of irradiation.

(9) The effect of irradiation on the properties and swelling characteristics of boron steels used as control-rod materials.

(10) The relative effects of thermal-neutron-induced transmutation of elements and fast-neutron atom-displacement damage in steels irradiated to extremely high neutron doses.

Detailed investigations of these topics will necessitate considerable time and effort but it is imperative that they be carried out if a complete understanding of the problem is to be obtained. The continuing increase in the number of nuclear reactors and the consequent increase in the irradiation facilities available, coupled with improvements in techniques for measuring neutron fluxes and spectra in reactors, will undoubtedly enable more rapid progress to be made in future towards elucidating the various facets and understanding of the phenomenon of radiation damage in steels.

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The solubility of carbon in molten iron–nickel alloys

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SYNOPSIS

The solubility of graphite in iron–nickel alloys has been re-determined at 1350°C. Deviations from ideal behaviour are found and these are interpreted to indicate a negative heat of mixing in liquid iron–nickel alloys having a maximum value at 75 at-%Ni. It is suggested that short-range ordering may be present in the melts.

1675

INTRODUCTION

THE RE-DETERMINATION of the solubility of carbon in liquid iron–nickel alloys was undertaken in the hope that the dissolved carbon could be regarded as an 'indicator' of any lack of ideality of the iron–nickel solvent. The earlier measurements of Turkdogan *et al.*[2] show that the carbon solubility does not vary in a simple manner with the composition of the iron–nickel solvent, particularly at low temperatures. Their solubility/composition relationship is, however, insufficiently well defined for detailed examination, and we have therefore re-determined the carbon solubility in iron–nickel alloys at a low temperature (1350°C) at which deviations from ideality would be expected to be most pronounced.

EXPERIMENTAL

The iron–nickel alloys were brought to equilibrium with graphitic carbon by holding them in graphite crucibles at 1350°C in an atmosphere of oxygen-free nitrogen. In each experiment an accurately weighed mixture of pure iron wire and electrolytic nickel foil was packed into a soft graphite crucible and raised into the constant temperature zone of a furnace controlled at 1350±3°C. Samples of the melt were sucked into a silica tube fitted with a syringe bulb at its upper end and containing a copper rod to limit the rise of molten alloys. After sampling, the silica tube and sample were rapidly quenched into water.

The quenched samples were cleaned by filing and analysed for carbon by a standard combustion method. Periodic sampling showed that equilibrium was generally reached within 1·5 h, and after equilibrium had been attained three independent samples were taken for analysis which gave agreement to within ±0·06 wt-%C. Longer times were required to reach equilibrium for alloys near the 30% and 75%Ni compositions which were therefore equilibrated for at least 5 h. The carbon contents are given in Table I.

Analyses of selected samples for iron and nickel by standard methods showed no detectable change in the iron/nickel ratio for melts held for times up to about 8 h. A small but insignificant loss of iron was detectable after longer times. The iron and nickel contents given in Table I are therefore calculated from the pure metals charged.

The results are plotted in Fig.1 as the logarithm of the carbon atom fraction on a basis of the composition of the iron–nickel solvent, for convenience of later discussion. The solubility of carbon in pure iron has been taken from Turkdogan and Leake,[3] and results of previous solubility determinations in iron–nickel alloys at 1350°C[2,4] are given for comparison.

DISCUSSION OF EXPERIMENTAL RESULTS

The carbon solubilities in iron–nickel alloys determined in the present investigation, Fig.1, appear self-consistent and are in satisfactory agreement with the results of Schichtel and Piwowarsky.[4] Some of the solubilities determined by Turkdogan *et al.*[2] are significantly lower than those obtained in the present work, and it seems probable that they allowed insufficient time for saturation to be attained for alloys near the 30% and 75%Ni compositions at which we have found the rate of carbon pickup to be comparatively slow.

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TABLE I Composition of carbon saturated iron–nickel alloys at 1350°C

	Weight percentage												
Iron	84·8	71·3	60·5	48·7	39·0	28·0	25·8	23·6	19·7	18·2	16·9	9·4	9·2	0
Nickel	10·9	25·0	36·2	48·7	58·8	70·1	72·5	74·6	78·5	80·0	81·3	88·7	88·9	98·0
Carbon	4·33	3·68	3·35	2·57	2·26	1·90	1·75	1·80	1·84	1·78	1·83	1·86	1·88	2·04

INTERPRETATION

Regular solution treatment

As has been suggested by Darken,[5] the behaviour of dilute solutes in binary solvents may conveniently be discussed from an equation derived from the ternary Gibbs–Duhem relation. If applied to the present system it gives the logarithm of the carbon solubility in a binary Fe–Ni solvent as:

$$\log x_c^{Fe-Ni} = x_{Fe} \log x_c^{Fe} + x_{Ni} \log x_c^{Ni} + \frac{\Delta G^E_{Fe-Ni}}{2{\cdot}303RT} \quad \ldots(1)$$

where x_{Fe}, x_{Ni} are the mole fractions of iron, nickel, respectively in the solvent
x_c^{Fe}, x_c^{Ni} are the molar solubilities of carbon in iron, nickel respectively
ΔG^E_{Fe-Ni} is the excess free energy of mixing of the binary solvent
R is the gas constant = 1·986 cal/mole/°C
T is the absolute temperature in °K.

This equation is strictly true only for dilute solutes which form regular solutions in the binary alloys, and these limitations are discussed subsequently. If the excess free energy of mixing in the binary solvent ΔG^E_{Fe-Ni} is zero, equation (1) reduces to:

$$\log x_c^{Fe-Ni} = x_{Fe} \log x_c^{Fe} + x_{Ni} \log x_c^{Ni} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

an equation previously derived by Wagner[6] for solution in ideal binary solvents.

In Fig.1 equation (2) is represented by the dashed line and the divergence of the experimental curve from this line is a measure of the deviation from ideal behaviour. If the solutions obey equation (1) the divergence is clearly equal to $\Delta G^E_{Fe-Ni}/2{\cdot}303RT$, but the applicability of the equation to this particular system must be considered.

Effect of non-randomness

The effect of varying co-ordination number and non-randomness of solubility in binary solvents has recently been assessed by Alcock and Richardson[7] and applied to dilute solutions of oxygen and sulphur in molten iron–nickel alloys. For convenience of comparison with the present study, values of the relative activity coefficient γ' taken from their publication are replotted in Fig.2 together with those calculated from our Table I (the relative activity coefficient, γ', is derived from the solubilities of the solute atom A by the equation:

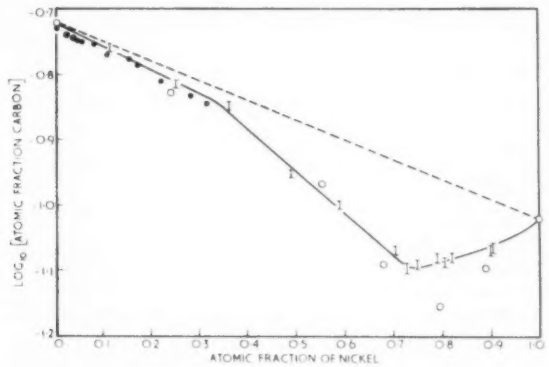
$$-\log \gamma'_A = \log x_A^{Fe-Ni} - \log x_A^{Fe}$$

and its use simply translates the experimental values of $\log x_A^{Fe}$ to a common origin and leaves the deviations from the ideal dashed curves unchanged). These authors assume zero heat of mixing in the iron–nickel binary solvent and hence zero ΔG^E_{Fe-Ni}* and ascribe the marked positive deviation in the oxygen solutions to a preferential iron–oxygen grouping due to a greater iron–oxygen than a nickel–oxygen attraction. No conclusion was reached concerning the sulphur solutions.

An indication of the attractions of iron and nickel for carbon, sulphur, and oxygen can be obtained from the magnitudes of the relative activity coefficients in pure nickel. These are presented in Table II together with data for carbon in liquid iron–manganese and iron–cobalt solvents.

The absence of any significant deviation from ideality of the behaviour of carbon in the iron–manganese and iron–cobalt solvents suggests that the values of $\log \gamma_A^{X'}$ of −0·16 and +0·19 respectively reflect differential solvent-solute interactions ($\epsilon_{Fe-A} - \epsilon_{X-A}$) which are too small to influence the solution behaviour of carbon. From this, the slightly greater values of $\log \gamma_A^{X'}$ of +0·31 and −0·35 for carbon and sulphur respectively in iron–nickel solvents would similarly not be expected to indicate any marked differential solvent–solute interactions leading to extensive deviations from ideal behaviour of the solutes. The fact that considerable deviations are found may then be attributed largely to non-ideal behaviour of the iron–nickel solvent.

The large positive value of $\log \gamma_A^{X'}$ for oxygen in iron–nickel solvents (+1·61) no doubt represents a stronger iron–oxygen than a nickel–oxygen attraction. This leads to the preferential iron–oxygen grouping which Alcock and Richardson[7] predicted from heat data and gives rise to much of the observed deviation from the ideal solution behaviour of oxygen. The difference in the cause of the deviations of the iron–nickel solvent containing carbon and sulphur from these containing oxygen is particularly apparent in the range 0–33 at-%Ni, Fig.2, in which the practically ideal solution behaviour of carbon or sulphur is contrasted with the strong deviation of oxygen solubility. If, in the solutions of carbon and sulphur in iron–nickel solvents, the differential solvent–solute inter-



1 Present work
● Schichtel and Piwowarsky[4]
○ Turkdogan *et al.*[3]

1 *Variation of the atom fraction of carbon at saturation in a binary iron–nickel solvent at* 1350°C

* A valid assumption which is exactly true for regular solutions.

TABLE II Interactions in liquid ternary iron solutions

Solution Fe–*X*–A	Temperature, °C	Log $\gamma_X^{A'}$ $=\log(x_A^{Fe}/x_A^X$	Maximum deviation of log $\gamma_A^{X'}$ from ideality
Fe–Mn–C	1350	−0·16	−0·02
Fe–Co–C	1350	+0·19	+p·02
Fe–Ni–C	1350	+0·31	+0·15
Fe–Ni–S	1550	−0·35	+0·10
Fe–Ni–O	1600	+1·61	−0·27*

* This figure represents the maximum deviation from ideality of the predetermined points.

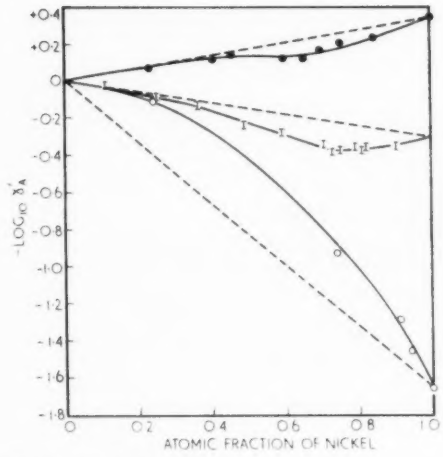
actions are sufficiently small to have little influence on the solution behaviour of the solute, the observed deviations may reasonably be interpreted to indicate negative heats of mixing for liquid iron–nickel alloys according to equation (1), which are most prominent between 33 at-% and 100 at-%Ni.

The numerically greater heat of mixing calculated from the carbon solutions (e.g. −1·11 kcal/g-mol, cf. −0·63 kcal/g-mol from sulphur data at 75 at-%Ni) is no doubt due to the difference in temperature of the determinations and to the errors introduced by applying equation (1) to carbon solutions which are not strictly dilute, and in which the greater co-ordination of carbon would give an apparently greater heat of solution.[7] Any such negative heat of mixing of the high nickel binary solvents should produce an inflexion in the curve for oxygen solutions due to its effect in opposition to that of iron–oxygen clustering, but the data are too sparse to verify this.

The heats of mixing of liquid iron–nickel alloys calculated from carbon solubilities may be checked with a direct calorimetric determination at the 48·4 at-%Ni composition, at which Sauerwald *et al.*[1] obtained a heat of −0·48 kcal/g-mol at 1530°C in satisfactory agreement with −0·53 kcal/g-mol calculated from Fig.1. However, heats calculated from Fig.1 are incompatible with the recent values obtained indirectly from activity measurements by Speiser *et al.*[10] whose heat of mixing showed a maximum value of −7·8 kcal/g-mol at the 60 at-%Ni composition. This is abnormally large for a system showing no compound formation and no doubt arises from slight errors in the experimental measurement of the variation of activity with temperature on which the calculation of the heat of mixing sensitivity depends, and which is also reflected by the surprisingly large calculated negative entropy of mixing of −2·4 cal/°C/g-mol.

It is noticeable that the data for carbon solubility, Figs.1 and 2, can be closely approximated by three linear segments intersecting at the Fe_2Ni and $FeNi_3$ compositions, but whether this is also true for the similar sulphur solutions cannot be ascertained due to the greater error of the individual points. More definite examples of discontinuous behaviour have been noted earlier by Darken[5] and Darken and Gurry[8] for hydrogen and carbon in binary solvents, who have suggested that this might reflect ordering at compositions corresponding to the discontinuities.

If the angular form of the solubility curve for carbon and possibly that for sulphur is due to ordering, this would indicate marked short-range ordering in liquid alloys corresponding to the $FeNi_3$ composition. This suggestion received some support from the existence of ordering in solid alloys at this composition, and the



I Carbon at 1350°C, present work
● Sulphur at 1550°C, Alcock and Richardson[7]
O Oxygen at 1600°C, Chipman and Wriedt[9]

2 *Variation of the relative activity coefficient, γ′ in a binary iron–nickel solvent*

minimum in the liquidus indicates a greater negative departure from ideality of the liquid, i.e. a greater tendency to ordering. The possible slight ordering at the Fe_2Ni composition has no solid state counterpart.

CONCLUSIONS

Although the solubility of carbon in liquid iron–nickel alloys is substantial, it is considered that the solutions can usefully be discussed with reference to the Darken equation for dilute solutions. This suggests that at 1350°C the binary iron–nickel solvent is not ideal and has a maximum negative heat of mixing of about −1·1 kcal/g-mol at 75 at-%Ni. The variation in carbon solubility could be taken to indicate short-range ordering in the iron–nickel solvent at the $FeNi_3$ and possibly also at the Fe_2Ni compositions, but the evidence is inconclusive.

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The influence of furnace pressure control on the performance of regenerative reheating and heat-treatment furnaces

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SYNOPSIS

The use of furnace pressure control to achieve marked fuel economies has been shown in trials made on two gas-fired air-regenerative bogie-hearth furnaces where it was found that the gas consumed both in reaching temperature and in subsequent soaking is considerably reduced with increasing furnace pressure. This continues to obtain until an optimum pressure is reached, beyond which gas consumption again increases, although the effect of excessively high pressures is much less marked than correspondingly low pressures. At the optimum pressure the whole of the furnace chamber and most of the regenerators are at a positive pressure.

The rate of air infiltration is shown to vary roughly in inverse proportion to the square of the furnace pressure, but the volume of expelled products varies much less rapidly with changes in furnace pressure and, at high pressures, tends to reach a limiting value. The CO_2 content of the waste gases was found to vary with both the furnace pressure and the gas-flow rate which emphasizes that CO_2 readings must be carefully interpreted.

It is concluded that on the majority of furnaces the use of automatic furnace pressure control can be fully justified. 1707

INTRODUCTION

IN RECENT YEARS furnace pressure control has received considerable attention. Although the influence of furnace pressure on production furnaces and on semi-works scale furnaces[1–3] has been exhaustively studied in OH furnaces both theoretically and practically, little work has been done on furnaces which operate at lower temperatures. This is unfortunate since it is in this sphere that the full benefit can be derived from the application of chamber pressure control. One of the main conclusions of the OH studies is that it may be difficult to operate production furnaces at the optimum pressure because of the damage caused by excessive flame 'sting' from the doors. At lower temperatures the operating conditions are less severe and this limitation no longer applies.

The function of furnace pressure control is to establish and maintain conditions of positive pressure within the furnace chamber for the purpose of eliminating or minimizing air infiltration since this has the effect of:

(i) reducing the efficiency of the furnace because it is necessary to consume additional fuel to raise the temperature of the cold infiltrated air to the same level as that of the furnace chamber

(ii) reducing the rate of heat transfer to the load with a consequent increase in heating time and fuel consumption. This operates because any cold infiltrated air, having a greater density than the hot gases in the furnace chamber, would tend to stay at hearth level.

The control of the pressure in the furnace chamber should be regarded as a necessary foundation for the efficient control of the other operating variables. Thus the elimination of cold infiltrated air at hearth level would increase the degree of circulation of combustion products in the working chamber and result in a much more uniform temperature distribution. Secondly, by eliminating air infiltration, the total air used in combustion is that supplied to the burners, and thus the furnace atmosphere can be adjusted to produce

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oxidizing or reducing conditions, as required, solely by regulation of the air/gas rates at the burners.

General discussions of the effect of furnace-pressure control on performance have appeared[4] but very few quantitative studies seem to have been made.[9, 12] The series of trials here described were carried out on works production furnaces with the primary object of determining the quantitative effect of different values of furnace pressure on gas consumption. Strictly comparative tests have been made covering a range of furnace pressures at three temperature levels, selected from the normal range of operating temperatures for the furnaces used. The general influence of furnace pressure on overall performance, especially with regard to temperature distribution, has also been the subject of observation.

In addition to these production trials, a number of tests were made to determine the influence of furnace pressure on the volumes of infiltrated air and expelled products. It is often assumed[2] that the amount of air infiltration in a furnace can be calculated from measurements of the CO_2 or O_2 content of the exhaust products, but this method is valid only if the whole of the furnace is at a negative pressure so that the only leakage taking place is that of air into the furnace.

However, this state rarely obtains in practice. Because of the buoyancy effect of the hot gases in the furnace chamber and regenerators, the pressure will increase progressively from the base of the regenerators to the roof. In most instances the damper is adjusted so that the upper part of the furnace is at a positive pressure, and part of the combustion products will be expelled from this region into the atmosphere. Air leaks into the lower part of the furnace which is at a negative pressure.

Under these circumstances, because an unknown proportion of the CO_2 or O_2 resulting from the combustion process has been lost from the furnace before reaching the exhaust flue, the volume of infiltrated air cannot be estimated from the analysis of the waste gases alone. This method of calculation is equivalent to the construction of a CO_2 or O_2 balance on the assumption that neither CO_2 nor O_2 has been lost from the furnace. Measurements of the actual volume of exhaust gases are also required, and then, under conditions described later, the volumes of both infiltrated air and expelled products can be calculated. Bell and Thomas arrived at a similar conclusion while carrying out radioactive measurements of infiltration and blow-out in OH furnaces.[8]

PRODUCTION TRIALS

Description of furnaces (*see* Fig. 1)

Investigations were made on a heat-treatment furnace 30 ft long × 12 ft wide × 9 ft high, and a forge reheating furnace 14 ft long × 7 ft wide × 7 ft high. Both are of the bogie-hearth reversing type, with air regeneration in multipass checkers below ground level. The forge reheating furnace has, in addition, a metallic tubular needle-type gas recuperator.

Both furnaces are of modern design, fired with cleaned coke producer gas at a calorific value of 132 Btu/ft³. Air is supplied from a blowing fan, the waste products being extracted by an induced-draught fan. The reversing equipment consists of two water-sealed gas reversing valves and a water-cooled air- and waste-gas reversing chest. The reversing gear can be set to operate automatically, at pre-determined time intervals.

The furnaces are robustly constructed, being encased from ground level to roof with firmly supported $\frac{3}{8}$-in. mild-steel plates. They are sand-sealed, with a sand trough arranged on each side of the bogie frame so that filling can be done when the bogie is withdrawn from the furnace. A heavy hematite iron support casting is built into the back wall, spanning the full width of the furnace and allowing the bogie to project, thus providing a means of sealing the back of the furnace from the outside. The front end of the bogie projects beyond the door so that this can be sealed in a similar manner when the door is closed.

Normal precautions had been taken, therefore, in designing the furnaces to minimize air infiltration. They were also in an excellent state of repair having been in operation for less than two years.

Each furnace is fully instrumented, equipped with a hydraulic furnace pressure regulator and a furnace pressure recorder, a recording and integrating gas-flow meter, an air-flow indicator, and gas- and air-pressure indicators.

The gas-flow meter is of the ring-balance type measuring the differential pressure across an orifice plate. The air-flow indicator measures the draught produced at the throat of a venturi tube mounted on the fan inlet. In both instances the differential device is considered to be located in a good position; there are no obstructions in the immediate neighbourhood of the venturi tube, and the orifice plate is fitted in a convenient run of straight main whose length exceeds 30 pipe dia. There can be little doubt that under these circumstances both air- and gas-flow measurements are reasonably accurate; although, with the particular objective in mind, consistency is perhaps more important than absolute accuracy.

The original instrumentation included a recording electronic temperature controller and hydraulic regulator operating a proportional opening regulating valve in the gas main which was linked mechanically to a similar valve in the air line. In the case of the reheating furnace (normally operated with all burner valves fully open) this arrangement proved capable of maintaining a constant air/gas ratio. A higher degree of temperature uniformity is, however, required for the larger heat-treatment furnace, and this is normally achieved by manual setting of the individual burner valves. The accuracy demanded in these trials prompted the installation of a hydraulic ratio regulator on this furnace to operate the air valve and maintain a constant air/gas ratio, independent of the settings of individual burners.

Description of trials

Preliminary work had been carried out to determine the conditions necessary to provide reliable data and because of the many possible variants involved, it was deemed essential that clearly defined conditions should be established which would be reproducible throughout each set of trials.

Initial furnace conditions

It was apparent that initial furnace conditions could have a marked influence on the results obtained, and efforts were therefore made to ensure that suitable

initial furnace conditions were achieved for each set of trials.

For the tests at the temperature level of 760°C on the heat-treatment furnace a convenient means of establishing the desired conditions was afforded by the frequency of a particular type of hardening operation in which the weight and distribution of the load was consistent, the procedure adopted for this series of trials being as follows.

The bogie was withdrawn from the furnace immediately after completion of the hardening operation, the door being left fully open and the gas supply shut off. The air supply, however, was maintained at the full flow of 120000 ft³/h with the automatic reversing gear in operation on a 10-min cycle. The object of the latter part of the procedure was to cool the furnace chamber and regenerators as rapidly and uniformly as possible before the start of the test heat some 8 h later.

The 890°C series of tests which were also carried out on the heat-treatment furnace, were arranged to follow a regular operated 760°C annealing cycle in which the periods of soaking were sufficiently long to achieve a condition of thermal equilibrium in the furnace. The load and furnace were then allowed to cool slowly under natural conditions to a temperature of 300°C. At this stage the bogie was withdrawn and the furnace door closed. The test heat was begun after a further interval of about 12 h.

For production reasons a different method of attaining the 'basic' condition was necessary in the 1230°C trials on the forge reheating furnace. The furnace and load were thoroughly soaked at 650°C over a period of 20–30 h with the furnace pressure set at +0·025 in. wg. This initial conditioning temperature was selected as being the lowest at which safe and satisfactory reversal could be achieved. Automatic reversal was employed using a 10-min cycle.

Temperature measurements

Three rare-metal thermocouples inserted through the front, side, and back walls of the furnace, and resting on the load, were employed during the tests in the heat-treatment furnaces. The load temperatures were recorded independently of the control equipment in a central pyrometer house. The control couple projects through the centre of the furnace roof, to about 3½ ft below the soffit of the crown, the temperature at this point being recorded on the controller which is mounted on the instrument panel adjacent to the furnace.

The temperature in the reheating furnace was measured by two thermocouples in a common sheath inserted through the centre of the back-wall to a distance of about 15 in. The temperatures of these couples were independently recorded.

Obviously these measurements are subject to some inaccuracies. In the heat-treatment furnace, differences between the load couples and the load itself will depend on the thermal resistance between couple and load, and on the rate of heat transfer to the load. The thermal resistance was reduced wherever possible by placing the couples in between the products forming the load. The rate of heat transfer and the error arising gradually decreased during the soaking period. In both furnaces the temperature registered by the control thermocouple was influenced by the furnace atmosphere, furnace brickwork, and the load.

However, despite the errors inherent in these normal production methods of temperature measurement, the experience gained during the preliminary work indicated that the degree of accuracy was sufficient to fulfil the requirement that the trials in each series should be truly comparative.

Furnace pressure measurements

In both furnaces chamber pressure was measured at a point on the vertical centre-line of the back-wall, at a height of 2 ft 6 in. above the hearth. Control was effected by the hydraulic regulator which operated a butterfly damper in the ducting leading to the exhaust fan. The impulse pipe was connected horizontally from the tapping point in the furnace back-wall to the measuring diaphragm of the regulator, which was situated well clear of the furnace, thus avoiding the necessity for a compensating pipe.

Furnace load

For the trials in each series to be reasonably comparative, efforts were made to provide loads of similar type, particularly with respect to weight and distribution for each temperature level under investigation. Such variations as were necessary did not unduly affect the results, as will be discussed later.

Procedure during heating

Throughout all trials the following general operational methods were adopted.

The air/gas ratios, as determined from meter readings indicating gas flow to the burners and air flow as delivered by the fan, were fixed at 1·50 and 1·35 on the heat-treatment and reheating furnaces respectively. These ratios, which are in excess of theoretical demands, were found necessary to ensure complete combustion since it had previously been observed that high positive pressures led to loss of air from the incoming regenerators.

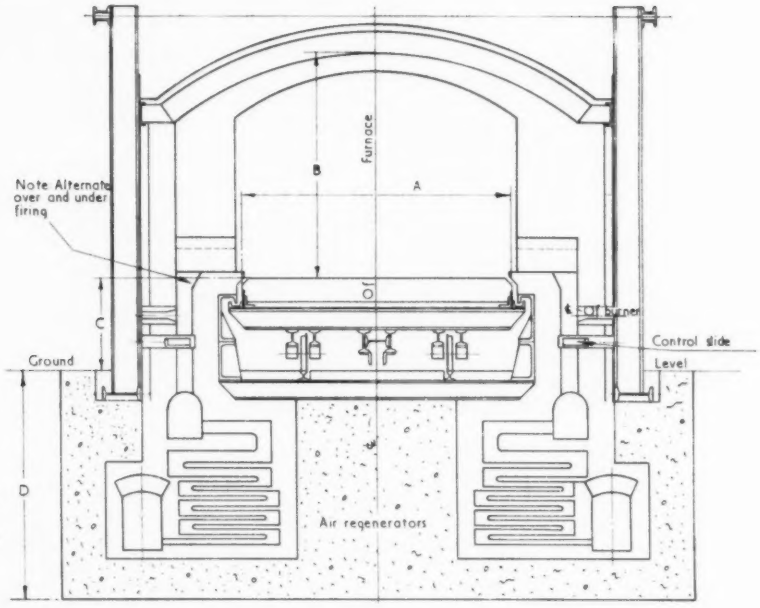
In all trials, the automatic reversing gear was operated with a 10-min cycle, this being brought into operation in the case of the heat-treatment furnace when the load reached a temperature of 600°C, while with the reheating furnace reversing was employed throughout the conditioning period at 650°C.

Some divergence in subsequent heating procedure was necessary, due to the different initial furnace condition adopted at each temperature level, as described below:

(i) 1230°C trials. During heating, the gas flow was maintained at the design maximum of 50000 ft³/h, with the automatic temperature controller set at 1230°C. On reaching this temperature, as measured by the control thermocouple, normal auto-control conditions operated.

(ii) 890°C trials. Similar heating conditions operated as for (i) except that in this case the gas flow design maximum was 75000 ft³/h.

(iii) 760°C trials. Early trials at this temperature were carried out under heating conditions similar to (ii) but this resulted in a situation at the start of the heating cycle in which the furnace chamber was at a temperature considerably above that of the loaded bogie. When the furnace was operated on automatic control in a normal manner, excessively long heating periods were obtained because the control



	A	B	C	D
Heat-treatment furnace, ft/in.	12·0	9 9	4 0	8 0
Reheating furnace, ft/in.	7 0	7 9	3 7½	9 0

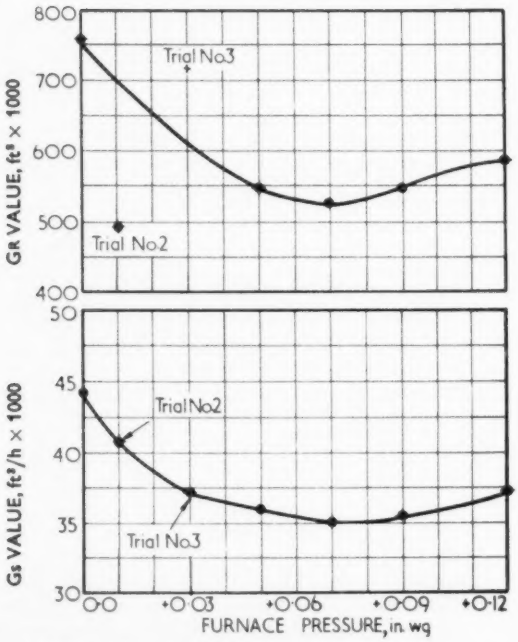
1 *Diagram of heat-treatment and reheating furnace*

thermocouple reached controlling temperature considerably in advance of the load.

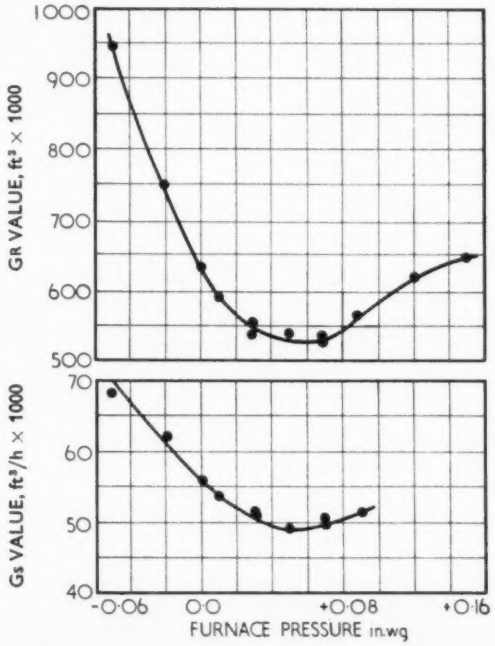
To counteract this undesirable effect, the gas-control valve was locked at the position of maximum flow rate during heating, the furnace being operated manually. When the temperature of the load reached the desired level, as measured by the load thermocouples, the automatic control equipment was brought into operation. At this point in the cycle the control-couple temperature was some 50–100°C higher than that of the load, and frequent small adjustments of the controller index were made manually to maintain the load at the required temperature until steady conditions were obtained, when normal auto-control operation was assumed.

Presentation of results

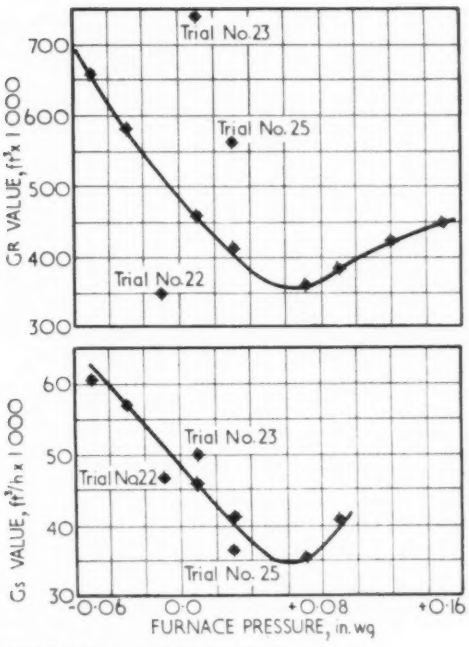
Two criteria have been selected for comparison of the performance of the furnaces at different chamber pressure levels, namely:



2 *1230°C trials; reheating furnace*



3 *890°C trials; heat-treatment furnace*



4 *760°C trials; heat-treatment furnace*

(i) The volume of gas consumed in reaching the required temperature under the 'standard' conditions previously described. This has been designated the GR value

(ii) the average rate of gas flow over the first part of the soaking period, referred to as the Gs value. The shortest soaking time of all the trials within each particular series has been adopted as the basis for comparison.

Figures 2, 3, and 4 relate to the above-mentioned criteria to furnace pressure.

TABLE I Temperature difference between load and control thermocouples after prolonged soaking, heat treatment furnace

Furnace pressure, in.wg	Load couple temperature °C	Control couple temperature, °C	Temperature difference, °C
+0·01	890	905	15
+0·03	890	900	10
+0·05	890	895	5
+0·07	890	890	nil
Above +0·07	...	...	nil
−0·01	760	785	25
+0·01	760	775	15
+0·03	760	765–70	5–10
+0·05	760	760–65	0–5
Above +0·05	...	...	nil

Discussion of results

1230°C trials

Throughout the series the furnace load varied from 20 to 24 tons. As will be seen from Fig.2, however, this variation does not appear to have affected the results to any appreciable extent. This is in accordance with expectations in view of the high ratio of thermal capacity of the furnace structure to that of the charge. The possible effect of load variation was revealed in preliminary work carried out before these recorded trials and the effect of a large variation in load is demonstrated in the 760°C trials which will be discussed later.

Referring to Fig.2, it is clear that there is an optimum value of furnace pressure in relation to gas consumption in reaching temperature (GR value) and over the first part of the soaking period (Gs value). This optimum value is shown to be about +0·07 in. wg.

The experimental results show that at low furnace pressures a small variation has a marked effect on the GR and Gs values, the effect decreasing as the optimum value is approached. It is evident, however, that the furnace can be operated over a comparatively wide range of pressure with little effect on the gas requirements. A variation of 0·04 in. wg above or below the optimum value has resulted in an increase in gas consumption of about 5%.

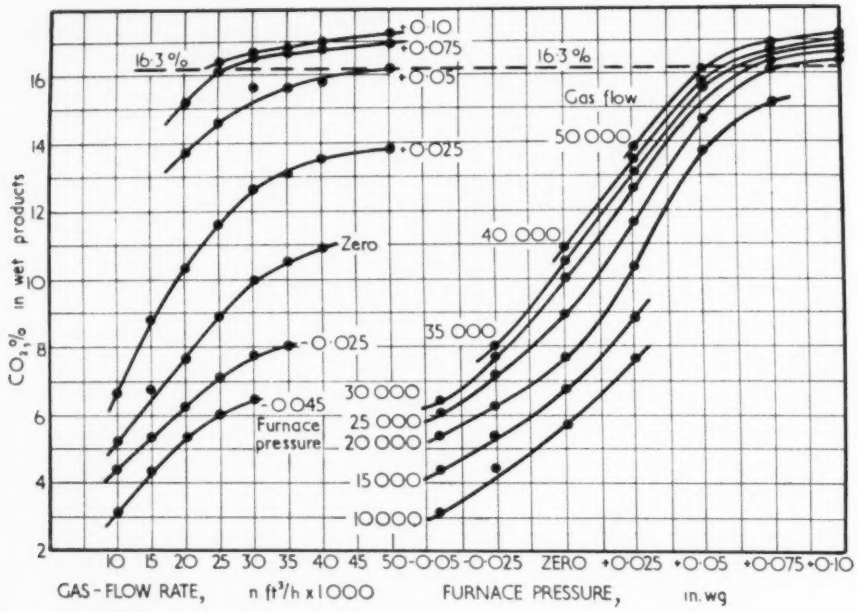
Two of the trials, i.e. Nos.2 and 3 were carried out to illustrate the effect of abnormal initial furnace conditions. In trial No.2 where the GR value is considerably lower than would be expected under normal conditions, the furnace and load were held at the conditioning temperature of 650°C for only 6 h, following cooling of the furnace from 1230°C. Under these conditions, it is clear that a reasonable state of equilibrium could not have been attained, the heat storage in the furnace structure being in excess of that obtaining under the standard initial conditions previously described. Similarly, equilibrium conditions had not been reached in the case of trial No.3 since the furnace had previously been cooled to 250°C and was subsequently maintained at 650°C for only 4 h. This resulted in the reverse effect being obtained to that in trial No.2, hence the abnormally high value of GR.

So far as the Gs values are concerned, the non-standard initial conditions do not appear to have had any effect as could logically be assumed.

890°C trials

Throughout all trials the furnace load ranged from 9 to 12 tons. This low loading, when viewed in relation to the size of the furnace, was occasioned by the physical dimensions of the products being heat treated. It is apparent from the results that the variation within this load range has been insignificant because of the high thermal capacity ratio of furnace to charge.

Figure 3 shows the same general relationship existing between gas consumption and furnace pressure for these trials as for the 1230°C trials, and the optimum pressure to yield minimum GR and Gs values at this different temperature level is about +0·06 in. wg. The results which have been obtained at furnace pressures above the optimum show that excessively high pressures have much less effect on the GR value than do excessively low pressures. This finding is to be expected from theoretical considerations as described by Leckie[1] who stated 'It is not always appreciated that the escape of flame involves far less thermal loss than that brought about by the air infiltration which results from increasing the draught to reduce flame escape to a small amount'. Corresponding data on Gs values could not be obtained since it was found impossible to maintain a constant pressure in excess of +0·09 in. wg over the 4-h soaking period due to the gradual reduction in gas-flow rate.



5 *CO_2 contents of exhaust products; reheating furnace*

A variation of 0·04 in. wg above or below the optimum value, resulted in a greater increase in gas consumption than was observed in the trials at 1230°C. To effect a difference in gas consumption of 5% of the assessed minimum, would necessitate the furnace pressure being maintained within ±0·03 in. wg of the optimum value.

760°C trials

With the exception of trials Nos.22 and 23, the loads throughout this series were reasonably constant within the range 48–52 tons.

Figure 4 shows the relationship between GR and Gs values and furnace pressure to be similar to that found in the 1230°C and 890°C trials. The optimum pressure would appear to be +0·06 in. wg as at 890°C. The results, however, show a smaller permissible variation in furnace pressure from the optimum, for maintaining the gas consumption within a nominal 5% of the assessed minimum.

Trials have been carried out which show the effect of wide variations in load and also departure from standard heating procedure, and these, trials Nos.22, 23, and 25, are included in Fig.4.

The loads for trials Nos.22 and 23 were 32 tons and 92 tons respectively. The results clearly show the expected effect on the gas consumption, both in reaching temperature under standard heating conditions, and in maintaining constant temperature throughout the soaking period under consideration, i.e. 5 h.

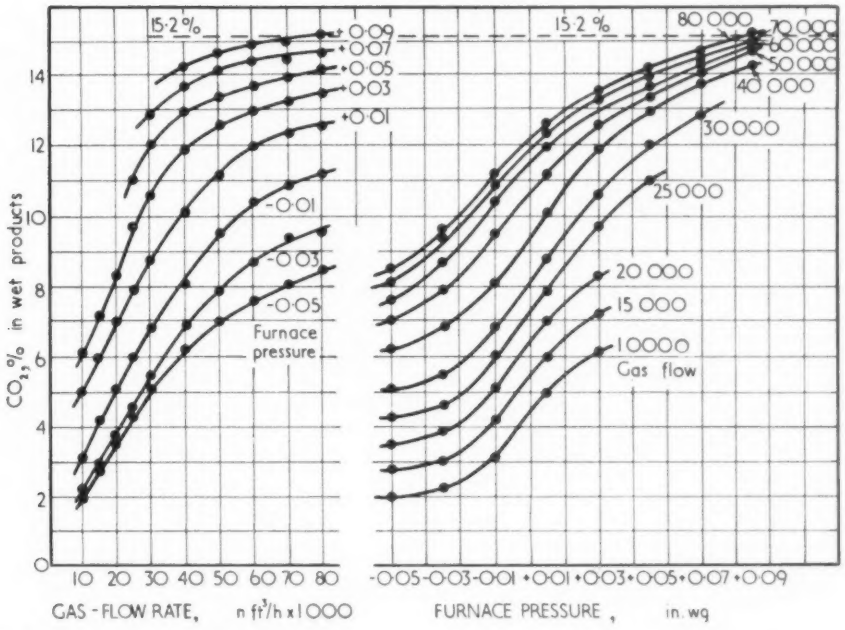
Trial No.25 illustrates the effect of abnormal heating procedure. In this instance heating of the furnace was carried out entirely under automatic control conditions which, due to the control couple reaching temperature well in advance of the load and a consequent decrease in gas flow, resulted in a slow gradual climb of the load temperature to the desired level. One effect of this, as will be seen from Fig.4, was an abnormally high GR value. On the other hand, the abnormally low Gs value which has been shown, is explained by the excessively long heating period, compared with standard conditions. This has resulted in the furnace reaching a state more closely approaching equilibrium at the start of the soaking period than in the other trials in this series.

Practical considerations

It has been observed throughout the trials that certain conditions, with respect to furnace design and maintenance, are necessary to achieve accurate and reliable furnace-pressure control.

The main consideration is to ensure that the design is such as to reduce the infiltration of air or expulsion of products of combustion to a minimum. Sand seals or other similar devices should be maintained in an efficient working condition and particular attention should be paid to the fit of doors. The aim should be to approach as close as practicable to a totally enclosed chamber, although brick-built structures with their attendant expansion and contraction of the joints cannot be expected to be fully satisfactory in this respect. The standard of brickwork maintenance should, therefore, be high. The importance of 'gas-tightness' has also been emphasized by Grey and Brooks.[12]

The effect of furnace pressure on the temperature uniformity throughout the furnace chamber is important in both reheating and heat-treatment furnaces but with, perhaps, greater emphasis on the latter. Under normal circumstances, control of uniformity along the length of the furnace can be achieved by adjustment of individual burner valves, although, except in specially designed furnaces, the operator has only a small measure of control over uniformity of temperature from the hearth to the roof. Throughout the trials it has been observed that, at negative chamber pressures,



6 *CO_2 content of exhaust products; heat-treatment furnace*

a temperature gradient exists from furnace hearth to roof, and even with prolonged soaking periods uniformity cannot be achieved. With progressively higher furnace pressures, the temperature differential is reduced, Table I illustrating the effects observed. Similar results have been reported for a 150-ton OH furnace.[10] It is clear, therefore, that with furnace pressures in the region of the optimum values, a closer control of temperature uniformity throughout the charge can be attained.

It is to be noted that optimum pressures of 0·06–0·07 in. wg which have been determined are of practical operating levels, i.e. they are not of unduly high pressures such as could possibly lead to discomfort or difficulties to operators by virtue of ejection of flame or hot gases in charging or discharging the furnace.

Economic considerations

Reheating furnace

Measurements of chamber pressure have been made on furnaces not fitted with automatic pressure control. In no instance was a furnace found to be operating at positive pressure. The usual value of the pressure at the point of measurement was −0·02 in. wg.

On this basis it has been calculated by extrapolation of the data given in Fig.2 that the possible reduction in gas consumption as a result of increasing the furnace pressure from −0·02 in. wg to the optimum value of +0·07 in. wg is about 38% and 30% for the GR and GS values respectively. Fuel savings of a similar order of magnitude have been reported on a recuperative forge furnace.[9]

Heat-treatment furnace

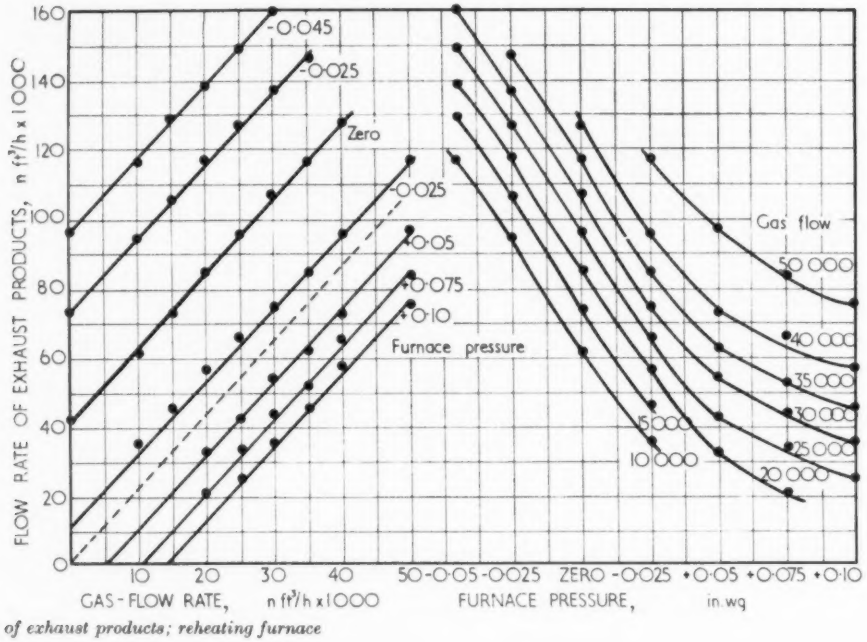
Similar measurements made on heat-treatment furnaces showed that some measure of pressure control is effected by the furnacemen who try to work throughout with the furnace under positive pressure, experience having shown this to be the most effective means of obtaining temperature uniformity. To attain these conditions, the practice is to work with the damper nearly closed, but in the absence of measuring and control instruments this means, in general, that during the heating period when gas-flow rates are high, the furnace pressure will be correspondingly and excessively high. When the soaking period is reached the pressure falls to a lower value due to the reduction in gas flow. It was found that the pressure actually varied between about +0·1 in. wg during heating and +0·04 in. wg during soaking.

Based on these departures from the optimum value of 0·05 in. wg the possible economy in gas consumption, determined from Figs.3 and 4 is shown to be about 10% on heating and 5% on soaking.

EFFECT OF FURNACE PRESSURE ON VOLUMES OF INFILTRATED AIR AND EXPELLED PRODUCTS

Description of tests

At each value of furnace pressure covered in the production trials, the CO_2 content and flow rate of the exhaust products were determined at various gas-flow rates up to the design maximum. The air/gas ratio to each furnace was maintained at a constant value throughout the period of the investigation by means of the ratio regulator and the air valve–gas valve linkage on the heat-treatment furnace and the reheating furnace respectively. The gas-flow meters, air-flow indicators, and furnace-pressure recorders were checked by means of an inclined gauge several times during the course of the determinations. All the measurements were made while the chamber temperature was between 700°C and 800°C in the case of the heat-treatment furnace or 1050 and 1200°C in the case of the reheating furnace.



7 *Flow rate of exhaust products; reheating furnace*

The waste gases were sampled by a perforated 1-in. bore pipe fitted in the right-hand regenerator outlet flue. This sampling pipe was connected to a chemical absorption type CO_2 recorder by small-bore plastic tubing, the waste gases being drawn through the tubing by a small ejector, actuated by compressed air, at a rate sufficient to clear the sampling system two or three times between successive analysis by the recorder. The accuracy of the instrument was checked occasionally during each determination by an Orsat apparatus.

The flow rate of the exhaust products was measured by a pitot tube also situated in the right-hand regenerator outlet flue. To reduce the amount of work involved, complete pitot tube surveys over the full cross-section of the flue were made in only a limited number of determinations which were chosen so as to cover the full range of flows encountered. The ratio of the average gas velocity in the flue to the velocity at the centre was found to be substantially the same in all these specially chosen cases. For the majority of the determinations, therefore, the pitot tube was fixed and the velocity measured at the centre of the flue only.

Presentation of results

The measured values of the CO_2 content and flow rate of the exhaust products at the various furnace pressure levels and gas-flow rates are set out in Figs.5–8. The values 16·3% and 15·2% given in Figs.5 and 6 respectively show the CO_2 contents which would result if there were no inleakage of air and no expulsion of gases from the furnaces.

Discussion of results

From the measurements made it is possible to construct curves showing the variation of the volumes of infiltrated air and expelled products with furnace pressure in the following manner. If I and E represent the volumes of infiltrated air and expelled products respectively, it is possible to obtain a value of $I-E$ at each furnace pressure level from a knowledge of the gas- and air-flow rates to the furnace and the flow rate of the exhaust gases. The sum of the volume of exhaust and expelled products is equal to the sum of the volume of infiltrated air and the volume of products resulting from the combustion of the gas with the air supplied from the fan. The theoretical air required for the complete combustion of the gas used is equal in volume to the gas burnt and the volume of the theoretical products formed in this manner is 1·8 times the volume of the gas burnt. Therefore, if D=rate of flow of exhaust products, nft³/h; I=rate of flow of infiltrated air; E=rate of flow of expelled products; G=rate of flow of gas to furnace; A=rate of flow of air from fan (*see* Fig.9); then

$$D+E=I+1{\cdot}8G+(A-G) \quad \ldots\ldots(1)$$

As during the primary trials, the air/gas ratio was fixed at 1·35 during the subsequent investigation on the reheating furnace, i.e. $A=1{\cdot}35\ G$ and therefore equation (1) reduces to

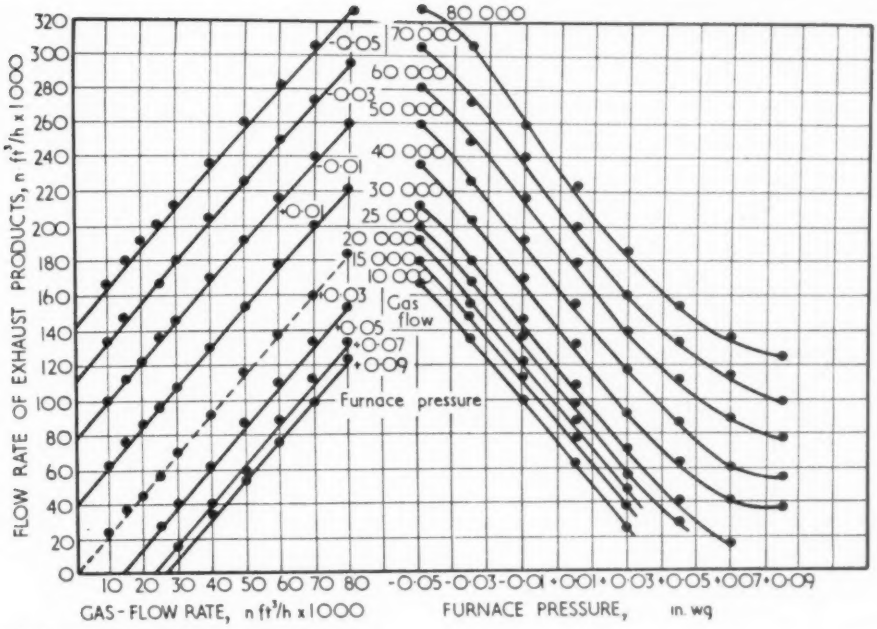
$$I-E=D-2{\cdot}15G \quad \ldots\ldots(2)$$

In the case of the heat-treatment furnace an air/gas ratio of 1·5 was maintained, i.e. $A=1{\cdot}5\ G$ and equation (1) reduces to

$$I-E=D-2{\cdot}3G \quad \ldots\ldots(3)$$

The values of $I-E$ found in this manner are plotted in Figs.10 and 11. The value of $I-E$ at a given furnace pressure is found to be constant and independent of the gas-flow rate, i.e. when the values of D at the same furnace pressure are plotted against G, the resulting graphs are straight lines, the slope of the lines being equal to the coefficient of G in equations (2) or (3).

It is also possible to calculate I and E separately at certain furnace pressure levels. For instance when the



8 *Flow rate of exhaust products; heat-treatment furnace*

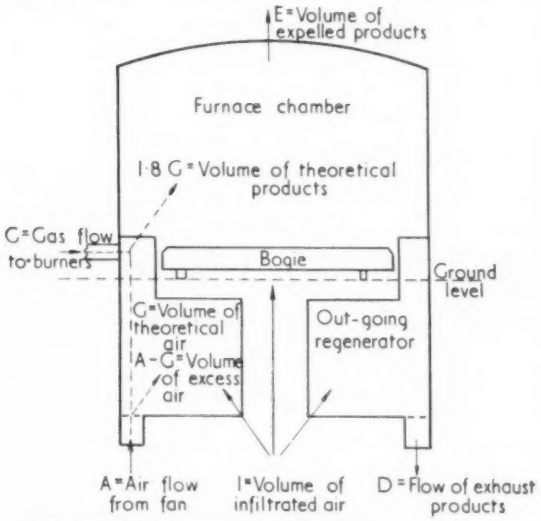
furnace pressure has been lowered until the whole of the furnace chamber and regenerators are under suction, the volume of expelled products, E, will be equal to zero and the corresponding value of I can then be found from equations (2) or (3). By means of a CO_2 balance it is possible to check whether the furnace pressure has been lowered to a sufficient extent for this condition to apply. Since E is equal to zero, no CO_2 will be lost from the furnace and, therefore, the volume of CO_2 in the exhaust products will be equal to the CO_2 formed during combustion. From the composition of the gas used it can be shown by elementary combustion calculations that the volume of CO_2 formed during combustion will be equal to 0·35 times the volume of gas burnt, and, therefore, the CO_2 balance can be expressed:

$$0{\cdot}35G = \frac{CD}{100} \qquad \ldots\ldots(4)$$

where C represents the percentage of CO_2 in the wet exhaust products. In the procedure previously outlined the CO_2 measurements give the percentage of CO_2 in the dry exhaust products, the steam formed by the combustion of the hydrogen and hydrocarbons in the gas having been condensed in the sampling system. However, since the composition of the gas is known, these dry values can be converted to CO_2 percentages in the wet products.

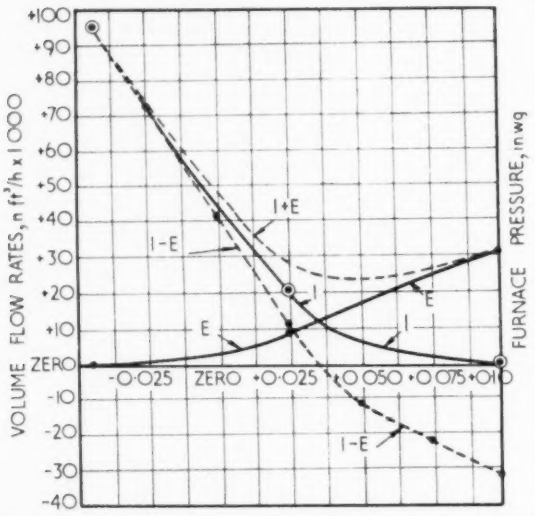
According to the bouyancy calculations based on the furnace and regenerator temperatures, the atmospheric line, i.e. the level in the furnace at which the pressure is equal to that of the outside atmosphere, reaches the crown of the furnace when the pressure at the point of measurement is reduced to −0·045 in. wg and −0·05 in. wg in the reheating and heat-treatment furnaces respectively. At these pressure levels the agreement between the left-hand and right-hand sides of equation (4) was within 5% on both furnaces at each value of the gas-flow rate investigated. Hence from equation (2) (reheating furnace) at a furnace pressure at the point of measurement of −0·045 in. wg $E=0$, $I-E=+95000$ and, therefore, $I=95000$ nft³/h. Similarly from equation (3) (heat-treatment furnace) at a furnace pressure at the point of measurement of −0·05 in. wg, $E=0$, $I-E=+144000$ and, therefore, $I=144000$ nft³/h.

I and E can also be determined separately when the atmospheric line is at hearth level. Under this condition there will be expulsion of products from the furnace chamber and air infiltration into the regenerators. If it is assumed that the volume of infiltrated

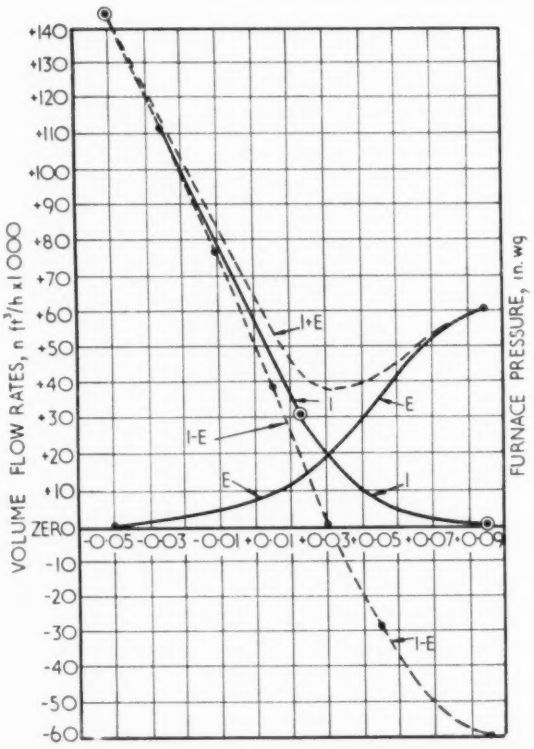

E = Volume of expelled products
Furnace chamber
1·8 G = Volume of theoretical products
C = Gas flow to burners
Bogie
Ground level
G = Volume of theoretical air
A-G = Volume of excess air
Out-going regenerator
A = Air flow from fan
I = Volume of infiltrated air
D = Flow of exhaust products

Flow rate into furnace = $1{\cdot}8G+(A-G)+I$
Flow rate from furnace = $D+E$
$\therefore D+E=1{\cdot}8G+(A-G)-I$

9 *Diagram showing derivation of flow relationships*



10 *Curves showing variation in volume flow rates of infiltrated air and expelled products with furnace pressure; reheating furnace*



11 *Curves showing variation in volume flow rates of infiltrated air and expelled products with furnace pressure; heat-treatment furnace*

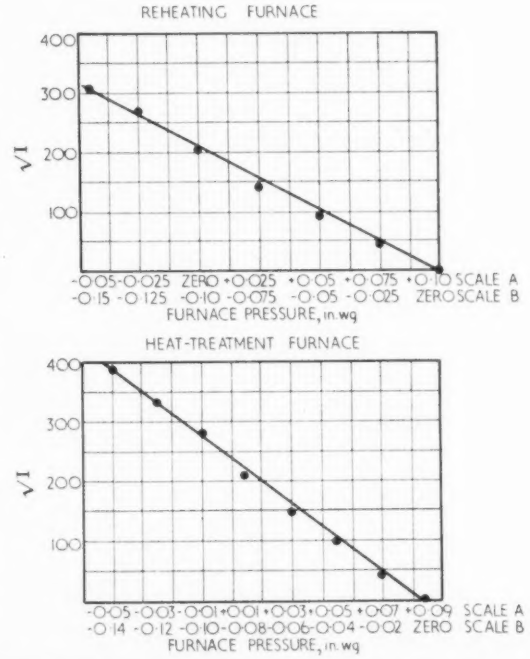
air is the same for the outlet and inlet regenerators, it is possible to set up a CO_2 balance which can be solved simultaneously with equation (2) or (3). The equation expressing the CO_2 balance is derived in the following way. The volume of CO_2 formed during combustion ($0{\cdot}35\ G$) will be equal to the CO_2 in the exhaust products ($C/100 \times D$) plus the CO_2 in the products expelled from the furnace chamber. This last term will be equal to the volume of expelled products E multiplied by the percentage of CO_2 in these expelled products which we may denote by C_E. The volume of air supplied from the fan to the base of the inlet regenerator is A nft³/h. The volume of air reaching the burner ports and taking part in combustion will, therefore, be equal to $(A+I/2)$nft³h assuming equal volumes of infiltrated air into each regenerator, and hence the proportion of CO_2 in the combustion products will be $0{\cdot}35\ G/(1{\cdot}8\ G+(A-G)+I/2)$. In this instance, when the atmospheric line is at hearth level, C_E will be given by this expression since no further infiltration occurs until the products enter the outgoing regenerator. This complete equation expressing the CO_2 balance is then

$$0{\cdot}35G = \frac{C}{100} \times D + E\ 0{\cdot}35G/(1{\cdot}8G+(A-G)+I/2) \quad \ldots\ldots\ldots\ldots (5)$$

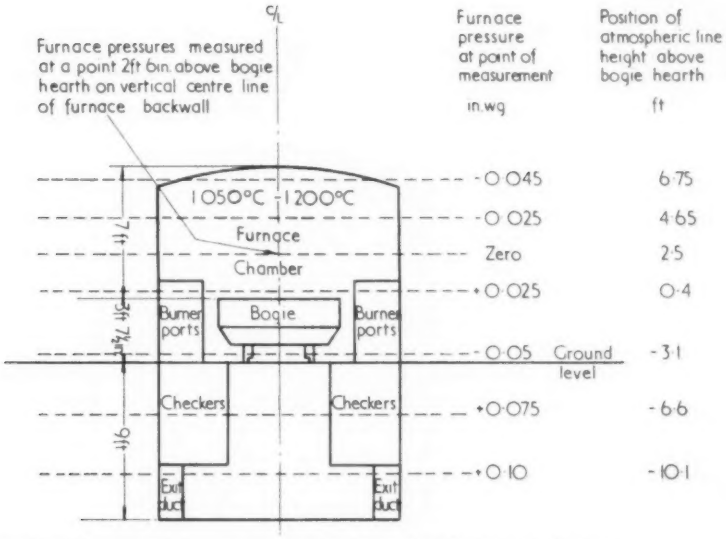
Consider first the reheating furnace. The buoyancy calculations show that the atmospheric line is at hearth level when the measured furnace pressure is $+0{\cdot}025$ in. wg. At this pressure $I-E=+11000$. Substituting $(I-11000)$ for E and $1{\cdot}35\ G$ for A in equation (5) gives:

$$I = \frac{150{\cdot}5G^2 + 770000G - 4{\cdot}3C.D.G.}{35G + C.D.} \quad \ldots\ldots\ldots\ldots (6)$$

The average value of I obtained from this equation is 19900 nft³/h and therefore E will be equal to 8900 nft³/h. Considering next the heat-treatment furnace, the atmospheric line is at hearth level when the furnace pressure at the point of measurement is $+0{\cdot}02$ in. wg. This was not one of the pressure levels investigated and, therefore, the corresponding values of $(I-E)$, C,



12 *Variation of $\sqrt{I}$ with furnace pressure*



13 *Positions of atmospheric lines at each furnace pressure level investigated; reheating furnace*

and D must be obtained by interpolation from Fig.6, 8, and 11. This gives $I-E=18000$ and since $A=1{\cdot}5\ G$ equation (5) gives

$$I=\frac{161G^2+1\,260\,000G-4{\cdot}6C.D.G.}{35G+C.D.} \qquad \ldots\ldots(7)$$

In this case the average values of I and E obtained were 30500 and 12500 nft³/h respectively.

We also know that when the atmospheric line is forced down to the level of the regenerator exit ducts the whole of the furnace is at a positive pressure and I will be equal to zero. In the heat-treatment furnace this condition applies when the measured furnace pressure is 0·09 in. wg. At this pressure $I-E$ is equal to −60000 nft³/h and, therefore, if I is zero, E will be equal to 60000nft³/h. Owing to higher temperatures and slightly deeper regenerators in the reheating furnace, the furnace pressure must be raised to +0·01 in. wg. before this condition applies. The value of $I-E$ is then −31000 nft³/h and, therefore E will be equal to 31000 nft³/h.

It is impossible to calculate values of I and E separately at any other pressure levels without making several simplifying assumptions. For instance, when the atmospheric line lies between the hearth and crown of the furnace, C_E, the percentage of CO_2 in the expelled products can only be expressed by making assumptions as to the proportion of combustion products and of the air which infiltrates into the furnace chamber which are carried into the positive pressure region above the atmospheric line where expulsion of products occur.

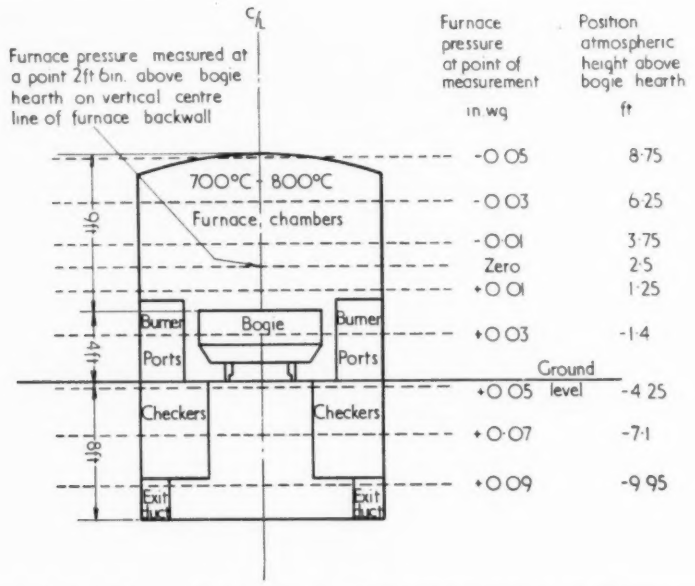
Bell and Thomas[8] demonstrated that, under these conditions, where the concentration of CO_2 in the expelled products is unknown, it can only be shown that the infiltration and blow-out volumes must lie between upper and lower limits.

However, from the curve of $I-E$ against furnace pressure and the known values of I and E when the atmospheric line is (*a*) at the crown of the furnace, (*b*) at hearth level, and (*c*) at the base of the regenerators, it is possible to construct approximate curves of I and E against furnace pressure. These are shown in Figs.10 and 11.

In Fig.12 the square-root of the volume of infiltrated air has been plotted against furnace pressure giving the straight line which would be expected from ordinary gas-flow laws for gases at constant temperature. Two furnace-pressure scales have been used. Scale A shows the furnace pressure at the point of measurement, i.e. 2 ft 6 in. above hearth level. Scale B shows the furnace pressure measured at the base of the regenerators so that when I is zero, furnace pressure on this scale is also zero. I can then be expressed mathematically in terms of furnace pressure measured on scale B and it can be concluded that the rate of infiltration of air into the furnace and regenerators is roughly proportional to the square of the amount by which the furnace pressure measured at the base of the regenerators falls below atmospheric pressure.

CONCLUSIONS

Reference to Figs.2, 3, and 4 show that the gas consumption does not reach the minimum value until the furnace pressure has been raised to a level at which the whole of the furnace chamber and a part of the regenerators are at a positive pressure. Figures 13 and 14 show the approximate positions of the atmospheric line, i.e. the level at which the pressure inside the furnace is equal to atmospheric pressure, for each pressure level investigated, as calculated from measured furnaces and checker temperatures. For both the reheating furnace and the heat-treatment furnace the minimum gas consumption is obtained when the atmospheric line is forced well down into the regenerators. A similar result was found in trials made on a model furnace.[3(iii)] Here the atmospheric line was at sill level when the roof pressure was +0·03 in. wg equivalent to 0·08–0·10 in. wg in production furnaces, and the trials showed that at higher pressures the rate of heat transfer to the hearth with a constant heat input continued to increase. The same effect was observed on a glass furnace.[5] The explanation offered



14 *Position of atmospheric lines at each furnace pressure level investigated; heat-treatment furnace*

was that the heat loss due to leakage outwards is much less serious than that due to leakage inwards which was later demonstrated theoretically by Leckie[1] and is fully confirmed by the present investigations. Oehler[9] also emphasizes this point. Not only is the effective heat loss per unit volume of expelled products less than the heat loss due to an equal volume of infiltrated air, but, for equal deviations in furnace pressure above and below the optimum value, the increase in the rate of flow of infiltrated air also is greater than the corresponding increase in the flow of expelled products (Figs.10 and 11). Thus the amount of air available for infiltration is unlimited, whereas the flow of expelled products is limited by the rate of fuel and air supply to the furnace and the fact that a high positive pressure is being maintained inside the furnace. The relative effects of air infiltration and expulsion of combustion products is further emphasized by a comparison of Figs.2, 3, and 4 with Figs.10 and 11. The minima on the $I + E$ curves occur at lower pressures than the minima on the GR and GS curves, which indicates that from the point of view of gas consumption it is necessary, within limits, to reduce air infiltration at the expense of an increase in expelled products.

Figures 5 and 6 show that CO_2 readings on the waste products must be carefully interpreted, since the CO_2 content varies with both the furnace pressure and the gas-flow rate. Similar relationships have been observed on OH furnaces.[6] J. S. Curphey obtained a series of results from an oil-fired furnace which showed that, without changing the oil and measured air flows, the waste-gas analysis can be varied by merely adjusting the furnace pressure. In view of this he suggested that an oxygen analyser in the waste gases should be used in conjunction with furnace pressure control for air/fuel ratio control.[11]

In the course of a detailed investigation into the performance of a continuous pusher-type reheating furnace, the magnitude of the CO_2 variation with fairly small changes in furnace pressure demonstrated to the authors the importance of close control of this variable.[12]

It is shown in Fig.12 that the rate of air infiltration is proportionate roughly to the square of the furnace pressure measured at the base of the regenerators. This relationship applies only to values of furnace pressure below zero. When the pressure at this point reaches zero or becomes positive with respect to atmosphere, infiltration of air ceases. The rate of air-flow through furnace brickwork has been shown to be proportional to the product of the wall area and the pressure differences across the wall,[7] thus $I \propto A \times \Delta p$, where I = rate of air infiltration, A = wall area, Δp = difference in pressure between atmosphere and base of regenerators.

The effect of changes in furnace pressure, however, is to adjust the position of the atmospheric level, and therefore the wall area under negative pressure where air infiltration occurs, i.e. $A \propto \Delta p$ which after substitution in the previous equation gives $I \propto (\Delta p)^2$. However, some air will infiltrate through openings such as sight holes and thermocouple holes where the pressure drop is a momentum loss, i.e. $I \propto \sqrt{\Delta p} \times A$ and therefore $I \propto (\Delta p)$.[1,5] This indicates that the rate of air inleakage into the furnace is not in exact proportion to the square of the furnace pressure, but as Fig.12 shows the square law relationship is a sufficiently close approximation.

Although the furnaces on which the trials were made are of modern design and in good repair, the amount of air infiltration which can occur is considerable. Since no brick-built structure can be made airtight it follows that furnace pressure control is necessary to limit air leakage. The influence of furnace pressure on gas consumption and general performance is most marked, and it would seem that on all but small or intermittently used furnaces, or furnaces of a special design such as those of recirculating type, the use of automatic damper control can be fully justified.

ACKNOWLEDGMENTS

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Corrosion of steels in liquid bismuth and lead

J. A. James, M.A., B.Sc., and J. Trotman, Ph.D.

SYNOPSIS

The corrosion of a variety of steels in liquid lead and bismuth has been studied in the temperature range 600–900°C, by measuring weight losses of steel pins after immersion in the hot side of a thermal convection loop. In uninhibited bismuth, low-alloy steels are more resistant to corrosion than 13%Cr–Fe or 18–8 stainless steel. Both nickel and manganese have an equally deleterious effect on the corrosion resistance of 2¼%Cr–1%Mo steel.

In bismuth inhibited with zirconium the best steels tested had extrapolated corrosion rates less than 0·005 in./year at 700°C with a 50°C temperature differential.

The corrosion of steels in uninhibited lead is about 40 times less than in uninhibited bismuth under similar conditions, and the corrosion is reduced by addition of 500 ppm titanium, with the same order of steel resistance as for the inhibited bismuth test. 1720

INTRODUCTION

THE PROPOSED APPLICATION of lead and bismuth in liquid-metal fuelled reactors has focused attention on corrosion due to thermal gradient mass transfer. This occurs where liquid metal circulates in a metal system having a temperature gradient between different parts of the system. Solution of the container occurs at the higher temperature followed by transfer to the cooler region where the solution supersaturates and excess solute precipitates. Eventually circulation in the system is prevented by failure of the container at the hot zone or by plug formation of deposited material at the colder region.

Tests with silica thermal convection loops have been carried out by Cathcart and Manley[1] for lead systems, and by Gurinsky *et al.*[2] for bismuth.

It has been found that the corrosion rate of steels by the liquid metals bismuth and lead can be reduced considerably by the addition of 50–500 ppm of titanium or zirconium[3] to the liquid metal. These additions are termed inhibitors. Weeks[4] has shown that low-chromium steels (2·5%Cr) are highly resistant to bismuth containing zirconium as inhibitor, and Horsley[5] has reported that the corrosion of 2¼%Cr–1%Mo steel in Zr-inhibited bismuth decreases with increasing nitrogen content. Furthermore, Horsley, using an electron diffraction method, showed that the protective film consists mainly of zirconium nitride. Taylor[6] has measured the corrosion rates of steels in both uninhibited and inhibited bismuth using the thermal mass transfer can technique, and is of the opinion that at least 50 ppm of zirconium is required in the bismuth for inhibition to take place.

The objects of the present work were

(i) to investigate the effect of constituents on the corrosion resistance of steels in both uninhibited and inhibited bismuth

(ii) to study, further, the inhibition process

(iii) to compare the corrosion rates of steels in lead and bismuth.

At the start of the investigation, the thermal mass-transfer can technique as used by Taylor[6] was employed. However, the accuracy of the method is very low, and this makes it impossible to distinguish between the corrosion rates of similar steels with only minor differences in composition.

The present paper outlines a thermal gradient pin test which has proved to be quick, and enables an accurate comparison of the corrosion of up to 20 steels to be made in a single test. Furthermore, by controlling conditions, absolute corrosion rates can be obtained.

MATERIALS

The steels listed in Table I with the exception of the 18–8 stainless, 13%Cr steel, and mild steel, were supplied by Firth and Brown Ltd. The analyses of the

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The authors are at Associated Electrical Industries (Rugby) Ltd, Rugby.

TABLE I Analysis of steels

Firth and Brown Steel cast no.	C	Si	Mn	Cr	Ni	Mo	V	W	Al	Nitrogen Sol (free)	Nitrogen Insol (fixed)	Total
CRM6												
O.1862	0·13	0·33	0·50	2·29	0·13	1·00	...	...	...	...	...	0·011
G.7512	0·11	0·12	0·52	2·12	0·12	0·89	...	...	...	...	...	0·009
O.7180	0·11	0·28	0·47	2·25	0·04	0·99	...	...	...	...	...	0·008
G.7519	0·11	0·02	0·51	2·08	1·04	0·92	...	...	...	...	...	0·012
G.7524	0·12	0·11	0·05	2·10	0·20	0·93	...	...	...	0·003	0·001	0·004
G.8528	0·12	0·01	0·95	2·09	0·26	0·92	...	...	...	...	...	0·012
G.7893	0·12	0·28	0·14	2·29	0·24	0·97	...	...	...	...	...	0·015
G.7895	0·11	0·22	0·99	2·25	0·05	1·05	...	...	...	...	...	0·010
G.7897	0·11	0·26	0·15	2·21	0·97	1·04	...	...	...	0·009	0·002	0·011
G.7898	0·11	0·25	0·98	2·26	0·99	1·02	...	...	...	...	...	0·009
G.7682	0·17	0·42	0·52	1·56	0·03	0·21	...	...	1·02	...	...	...
57918	0·33	0·48	0·24	0·99	0·47	...	0·08	1·81	...	...	...	...
89348	0·56	0·35	0·63	0·06	0·12	...	...	...	...	...	...	...
008853	0·43	0·19	0·22	3·11	...	...	0·48	9·86	...	...	...	...
19477	0·35	0·26	1·65	0·08	0·08	...	...	...	...	...	...	...
23021	0·36	0·28	1·75	0·15	0·11	0·40	...	...	...	...	...	...
86217	0·11	0·21	0·64	0·08	0·14	...	...	...	...	...	...	...
Mild steel	0·09	0·06	0·37	...	0·15	...	...	...	...	0·005	0·001	0·006
Mo–Cr	0·28	0·28	0·63	1·25	0·20	0·66	...	...	...	0·006	0·002	0·008
CRM6	0·09	0·47	0·48	0·85	0·19	0·54	...	...	...	0·010	0·001	0·011
Mo–V	0·18	0·41	0·45	0·09	0·38	0·70	0·25	...	...	0·002	0·012	0·014
ChromVa–W	0·16	0·04	0·43	2·66	0·17	0·61	0·78	0·72	...	0·002	0·015	0·017
Chrome–iron	0·08	0·16	0·28	13·04	0·21	...	...	...	...	0·021	0·001	0·022
18–8 stainless	0·08	0·40	0·17	18·90	8·30	...	...	...	...	0·033	0·002	0·035

Firth and Brown steels were supplied by the makers, but all nitrogen analyses were carried out in the authors' laboratory.

Nitriding of the CRM6 specimens was carried out at the Firth and Brown Research Laboratory by heating in ammonia at 510°C for 20 h.

Bismuth was supplied by the Metallurgy Division at Harwell. Zirconium wire (0·060 in. dia.) was obtained from Murex Ltd, while the magnesium was a Magnesium–Elektron product of 99·9% purity.

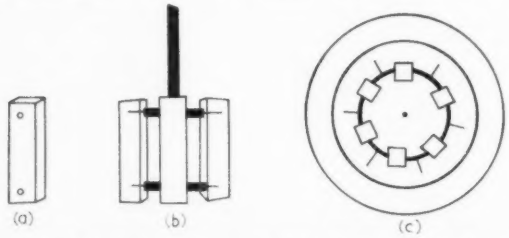
EXPERIMENTAL PROCEDURE

Bismuth tests

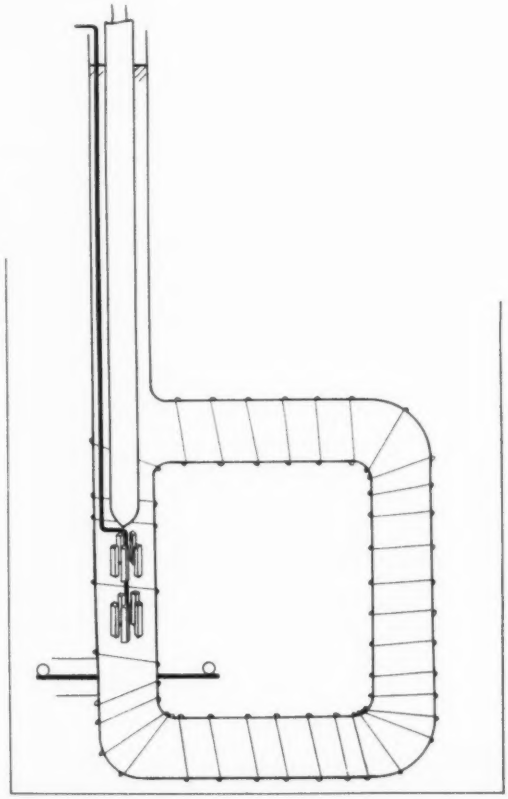
In the mild-steel thermal convection loop shown in Fig.2 the loop was heated electrically by beaded nichrome wire wound in two layers and a small section force-cooled to provide a suitable temperature differential. The loop was sealed by a solid plug of bismuth at the top of the open leg.

The bismuth was melted into the loop without pretreatment and was followed by the addition of about 2000 ppm of magnesium as deoxydant, and for inhibited tests about 500 ppm of zirconium was added, and sometimes 1000 ppm uranium to simulate reactor conditions. The large amount of magnesium was to ensure that the greater part of the uranium and zirconium was not oxidized and stayed in true solution.

The different steels were prepared in pin form (about $\frac{3}{32}$ in. × $\frac{3}{32}$ in. × $\frac{1}{2}$ in., Fig.1*a*) and were supported by a molybdenum wire (0·040 in. dia.) and maintained in a central position in the loop by molybdenum spacers (Figs.1*b* and *c*). The steel pins were abraded before test down to 4/0 grade emery paper and degreased with trichlorethylene before immersion in the bismuth containing magnesium.



1 a, b, and c. *Arrangement of steel pins and molybdenum supports*



2 *Thermal convection loop*

TABLE II Corrosion of steels in bismuth

Steel	Bi and Mg Corrosion at 700°C ΔT 50°C (mg/cm²/week)	Bi and Mg and Zr Corrosion at 700°C ΔT 50°C (mg/cm²/week)	Corrosion at 900°C ΔT 80°C (mg/cm²/week)
Group A			
89348	185	<1	144
G.7682	224	<1	225
57918	237	<1	270
Mo–Cr	207	<1	280
19477	238	<1	300
CRM6 (nitrided)	245	<1	330
86217	245	<1	366
Mo–V	245	<1	400
Mild steel	204	<1	400
23021	246	<1	400
CRMO	255	<1	510
Group B			
CRM6 (G.7524)	249	3	...
CRM6 (G.7895)	277	32	...
ChromVa–W	233	65	...
008853	257	65	...
Group C			
1·89%Si–Fe	177	55	...
13%Cr–Fe	298	87	...
18–8 stainless steel	417	87	...
Pure iron	213	195	...

The samples were placed in the hottest part of the loop (i.e. just above the force-cooled section), the test temperature being about 700°C with a 50°C temperature differential. However, the more resistant steels in inhibited systems were assessed at 900°C.

Tests varied from a few hours up to two weeks; after test the pins, which were always wetted, were removed and weight losses measured after removal of the adhering bismuth with hot mercury and a final cleaning in concentrated nitric acid.

In comparative tests, a platinum–13%Rh/platinum thermocouple was spot welded to the outer-loop wall at the sample level and was attached to a transitrol temperature controller. The hot zone containing the samples had an even temperature distribution (±3°C), enabling up to 20 steels, in two layers, to be tested together; usually a CRMO steel pin was placed in both layers as a standard.

For quantitative corrosion tests, the controlling thermocouple was placed *inside* the loop at the sample level, and was insulated by a narrow-bore silica tube sealed at the lower end (Fig.2). This technique was used since it was found that the temperature of the bismuth at the sample level, as measured by a thermocouple probe, was always lower than that given by the external thermocouple, the deviation depending on wall thickness and loop gradient.

To study inhibition, about 500 ppm of zirconium was then added to the same loop and the repolished pins replaced in the position occupied in the uninhibited test. This technique enables a quantitative estimate of the effect of zirconium on steel corrosion to be made. Results are recorded in Table II.

Lead tests

For the lead tests, the experimental technique was the same as for bismuth except that the loops were not heated with beaded nichrome wire since this heating system is incapable of withstanding the long test times or high temperatures required to obtain measurable weight losses.

TABLE III Corrosion of CRM6 steels in uninhibited bismuth

Steel	Weight losses at 600°C ΔT 100°C (mg/cm²/week)
CRM6	
G.7893	180
O.7180	195
O.1862	205
G.7895	210
G.7897	215
G.7524	215
G.7519	220
G.7898	230
G.7528	235

A more reliable means of heating was obtained by making the loop the secondary winding of an ac transformer system. However, this heating arrangement requires a different control system from that used with resistance heating, and to avoid this difficulty identical loops were used, and the relative position of the samples was always the same. The test temperatures and loop gradients agreed to within 5°C.

Tests were carried out at 800°C (ΔT 100°C) and 2000 ppm of magnesium was always added to the lead as a deoxydant. The relative corrosion rates of steels in uninhibited and inhibited lead and bismuth are recorded in Table VI.

Nitriding and carburizing of steels

Test pins made from Johnson Matthey spectrographically standardized iron sheet (0·012 in. thick) were nitrided by heating in ammonia at 500°C. Pairs of pins were removed from the hot zone at different times, one pin being used for the corrosion test and the other analysed for nitrogen.

Carburization of pure-iron pins was carried out by heating them in a pearlite carburizing mixture at 900°C in pairs, one pin for corrosion studies, the other for carbon analysis.

DISCUSSION

Experimental technique

Throughout the present investigation, the pin method has proved extremely useful. It provides a means of comparing corrosion rates of a large number of steels under identical conditions. The comparison is independent of variables such as time, temperature, loop-temperature gradient and rate of flow of bismuth, all of which must be accurately controlled when using other methods such as the thermal-transfer can technique.[6] There is a negligible possibility of atmospheric nitrogen or oxygen interfering with the corrosion rates by diffusion through the loop wall to the steel/bismuth interface of the test samples. Furthermore, results can be obtained in a comparatively short time since the dynamic nature of the system ensures that the bismuth at the sample level (the hottest part), is always unsaturated, resulting in continuous solution of steel components. Since solution of steel at the hot side is the rate-determining factor in mass transfer,[5,6] the results obtained from the pin method give a true comparison of steels under the proposed reactor conditions.

The possibility of mass transfer between individual samples cannot be discounted, but since the relative corrosion rates are reproducible, independent of time and the addition of new samples, it appears that this effect is very small.

TABLE IV Corrosion of iron in inhibited bismuth Temperature 750°C ΔT 50°C

Carbon, %	Nitrogen, %	Corrosion, mg weight loss
0·0041	0·0288	170
0·085	0·0288	30
0·234	0·0288	<1
0·0041	0·0385	141
0·0041	0·3100	33

Uninhibited bismuth tests

It is well known that steels containing large amounts of nickel and manganese, have very low corrosion resistance in bismuth systems due to the high solubility of these elements in liquid bismuth[4] (0·5 wt-% at 500°C). This is confirmed by the results in Table II.

The general trend observed for the corrosion rate is: 18–8 stainless steel >13%Cr–Fe >low alloy steels, this is in agreement with Taylor's work using thermal gradient cans.[6] However, Wilson *et al.*[7] have found from thermal loop tests that the high-chromium steels are the most resistant under uninhibited conditions, although in their tests, no deoxydant was added to the bismuth, and, probably, the corrosion rates of the chrome steels were lowered by oxide films at the steel/bismuth interface.

The effect of varying amounts of nickel and manganese on the corrosion resistance of CRM6 steel shows that they are equally deleterious (Table III) and a plot of corrosion rate against combined nickel and manganese content is a straight line. However, this 'bad' effect of nickel and manganese is only second order, and, in fact, CRM6 or any other steel tested cannot be regarded as satisfactory for containing bismuth under uninhibited conditions at 700°C.

It may be mentioned that preliminary experiments with samples of molybdenum, tungsten, and tantalum indicated that these metals are very highly resistant to attack by bismuth up to at least 800°C.

Inhibited bismuth tests

In all inhibited tests, a relatively high concentration (500 ppm) of zirconium was added to the bismuth although Taylor[6] had found that 50 ppm of the additive was sufficient for suppressing the corrosion. The large excess ensures that the corrosion rates are not affected by the availability of zirconium and are only dependent on the steel constituents.

For inhibited tests at 700°C, the steels can be classified into three main groups (Table II).

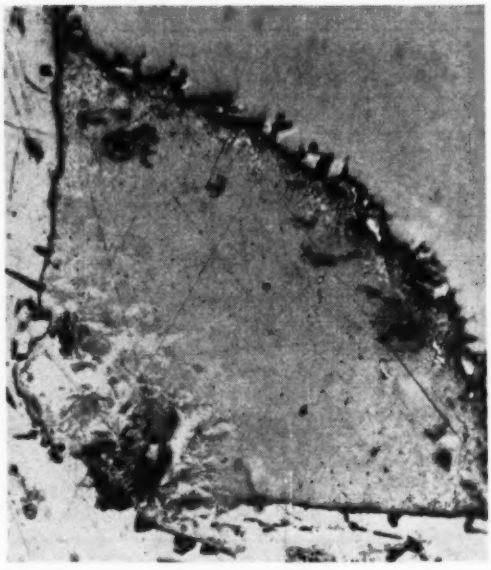
Group A Steels highly resistant up to at least 700°C, showing less than 0·005 in./year attack (extrapolated value) with a 50°C temperature difference.

Group B Steels having variable resistance, often showing 'pitted' attack (Fig.3).

Group C Steels always extensively attacked.

To classify the good steels (Group A) tests were carried out at 900°C, it being assumed that any steel which is resistant at this temperature will be very reliable at 500°C, the maximum temperature in one proposed form of Liquid Metal Fuelled Reactor.[8]

Zirconium suppresses the corrosion of CRM6 steel by a factor of 10 and this is similar to the difference in the plugging times which Horsley[5] observed for uninhibited and inhibited CRM6 loops at a maximum temperature of 625°C. This agreement confirms that solution of steel at the hot side of a loop is the rate determining factor in mass transfer.



3 *Corroded corner of a CRM6 steel pin, showing localized attack of 'pitting' at the corner* ×275

In Table V are results of a quantitative test in inhibited bismuth (500 ppm Zr: 2000 ppm Mg). 13%Cr–Fe was chosen for the series of tests since at 700°C its corrosion rate is appreciable, allowing results to be obtained in a short time. Furthermore, attack on this steel is uniform and not localized (pitted). The result reveals the following points:

(i) addition of 1000 ppm of uranium to the bismuth does not alter the rate of attack

(ii) the surface nature of the 13%Cr–Fe does not effect the corrosion rate. Types of surfaces examined were (*a*) oxidized, (*b*) unpolished, after cleaning with boiling mercury and concentrated nitric acid following a previous corrosion test

(iii) the corrosion rate is independent of time, indicating that oxidation of the zirconium by the silica thermocouple casing is insignificant at 700°C.

The inhibition process

It has been reported that zirconium nitride is the major component of the protective film at the steel/bismuth interface in inhibited systems, and that the formation of this film depends on the availability and mobility of the nitrogen in the steel. This is affected by the type and concentration of its alloying constituents[5] and is in good agreement with the corrosion rates in Table II which indicate that the resistance of the high alloy steel is much less than for the low alloy type.

The corrosion of CRM6 steel is reduced considerably by nitriding, but, apart from this case, there is little relationship between the resistance and the nitrogen

TABLE V Corrosion of 13%Cr–Fe Temperature 700°C ΔT 70°C

Bismuth contents ppm Zr	ppm Mg	ppm U	Treatment of steel	Time, h	Corrosion, mg/cm²/h
500	2000		Polished surface	6	6·8
500	2000		Polished surface	16	6·2
500	2000		Polished surface	16	6·2
500	2000	1000	Polished surface	17·2	6·7
500	2000	1000	Polished surface	6	6·5
			Heat treated:		
500	2000	1000	Polished	17	6·8
			Heat treated:		
500	2000	1000	Oxidized surface	6	7·0
			Heat treated:		
500	2000	1000	Unpolished	17	6·6

content, whether 'fixed' or 'free' These terms refer to the nitrogen analysis on the insoluble and soluble portion resulting from the solution of the steel in hydrochloric acid with addition of hydrogen peroxide. This suggests that constituents of the steel, other than nitrogen, may be important in the formation of the protective film. Table II shows a dependence of corrosion rate on the carbon content of the steel, except for the high alloy type, where, probably, the carbon is combined and is unable to react with zirconium.

Corrosion tests on Johnson Matthey pure-iron pins, to which were added varying amounts of nitrogen and carbon, revealed that both constituents are important in the formation of the protective film. The results (Table IV) indicate that carbon is much more effective than nitrogen in the inhibition process.

Lead corrosion

The corrosion of steel in uninhibited lead is about 40 times less than in uninhibited bismuth under similar conditions (Table VI) and this is in good agreement with the factor of 30 difference between the solubility of iron in lead[9] and bismuth[4] at 800°C. The low alloy steels are again the most resistant in lead, although the differences between the various steels are not so marked as in bismuth. Metallographic examination of a section of a mild-steel loop containing lead showed that the steel particles dispersed in the lead were much larger than those usually observed in bismuth, indicating that intergranular attack of steel, relative to solution is more severe in the former liquid metal.

INHIBITED LEAD

A freshly polished sample of zirconium wire was found to be insoluble in lead up to at least 900°C and so titanium was tried as inhibitor. Addition of 500 ppm of titanium to the lead reduced the corrosion considerably with the same order of resistance as for the bismuth–zirconium system. This indicates a similarity in the inhibition process, and so, probably, for lead–titanium, the protective film consists of the highly stable titanium carbide and nitride.

CONCLUSIONS

The pin technique is very satisfactory for comparing the corrosion rates of different steels in liquid metals.

TABLE VI Relative corrosion rates of steels in bismuth and lead. Temperature 800°C ΔT 100°C

Steel	Bismuth	Bismuth (+500 ppm Zr) $\times 10^{-2}$	Lead, $\times 10^{-2}$	Lead (+500 ppm Ti) $\times 10^{-3}$
0·3%C steel	1	1	3·2	1
Mild steel	1	1	3·4	1
CRM6	1·3	25	3·0	1
13%Cr–Fe	1·5	42	3·6	3·0
18–8 stainless steel	2·0	42	3·8	17·0

In uninhibited bismuth, the low alloy steels are more resistant to corrosion than 13%Cr–Fe or 18–8 stainless steel. A study of CRM6 steel showed that nickel and manganese are equally deleterious, but this effect on the corrosion is only second order, and, in fact, no steel tested can be regarded as satisfactory for containing liquid bismuth under uninhibited conditions at 700°C.

The corrosion of steel in bismuth is reduced considerably by addition of 500 ppm of zirconium due to the formation of a protective film of zirconium compounds on the surface of the steel. It has been found that carbon, as well as nitrogen, is important in the inhibition process, and that the degree of protection is affected by the alloying constituents in the steel such as W, Cr, Si, since these govern the availability of carbon and nitrogen at the bismuth/steel interface.

The corrosion of steels in uninhibited lead is about 40 times less than in uninhibited bismuth under similar conditions. The corrosion is reduced by the addition of 500 ppm of titanium, with the same order of steel resistance as for the bismuth–zirconium tests. It was found that liquid lead containing 500 ppm titanium in combination with the low alloy steel with available nitrogen or carbon was the most corrosion resistant system tested.

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The effect of mode of stressing in fatigue testing

B. Cina, Ph.D., B.Sc.

SYNOPSIS

Fatigue tests have been carried out on three different alloy steels, in pulsating, alternating, and fluctuating stress and it has been found that the results can best be represented on a modified Goodman diagram (based on the true fracture stress and the fatigue limit in alternating stress). The ability or inability of a steel to fail by fatigue testing in pulsating tensile or compressive stress can be fairly definitely predicted by such a diagram. Fatigue failures in both modes of pulsating stress have been obtained in certain instances in one of the steels. Fatigue tests in pulsating tensile, pulsating compressive, and alternating stress were accompanied by extrusion effects as have recently been found in certain non-ferrous alloys. Possible fatigue mechanisms are discussed. 1717

INTRODUCTION

SINCE MOST industrial fatigue failures probably occur through stressing in cycles of alternating tension and compression, most attention has been paid to this mode of stressing. However, to understand the fatigue process more fully, knowledge of what happens in pulsating tension or compression should be helpful.

Relatively little systematic work has been done on the effect of mode of stressing in fatigue. It seems to be fairly well established that a metal will withstand the repeated application of a tensile stress longer than alternating tensile and compressive stresses of the same magnitude, but there is still some doubt as to the effect of a repeated compressive stress without any alternating tensile stress.

Smith[1] obtained no fatigue failures in a series of carbon steels tested in pulsating compression, but only one such test was applied to each steel and in each case this resulted in plastic deformation of the test piece.

Haigh's[2] work on mild steel was also complicated by plastic deformation, the author stating that all his specimens failed in a ductile manner when tested in pulsating compression. Again, Haigh,[3] working with naval brass ($\alpha+\beta$ phases), obtained fatigue failures with a mean compressive stress on which was superimposed an alternating stress, but the latter resulted in a pure tensile stress in each alternate half cycle.

The Battelle staff book on fatigue[4] quotes some results obtained by others on a duralumin rod in pulsating stress in both tension and compression. The data given are meagre but suggest that stresses often well in excess of the 0·2% proof stress were applied to obtain fatigue failures in both modes of stressing.

To avoid plastic deformation during the test, Newmark *et al.*[5] had to cold work each of a number of materials in compression before fatigue testing in pulsating compression. This, however, vitiated comparison with their pulsating tension and reversed stress fatigue tests which were carried out on softened material. No fatigue failures in pulsating compression were obtained in three low-alloy steels, ductile cast iron, or brass, but failures were obtained in a structural steel, grey cast iron, and aluminium. Newmark *et al.*[5] also quote some Japanese work[6] in which a fatigue limit was determined in pulsating compression for a series of carbon steels. However, here again the stresses employed exceeded the (compressive) yield strength, often by a factor of almost two. Findley's[7] claims to have carried out fatigue tests and obtained fatigue failures in pulsating compression on a Ni–Cr–Mo steel (SAE4340) are not really justified since his tests were carried out in fully reversed stress on prior cold worked (compressed) material. Morrogh[8] has reviewed the effect of mean stress and stress range in the fatigue testing of cast irons. This seemed to show that cast irons and malleable irons could fail by fatigue testing in pulsating compression although the stresses employed by the several workers quoted would all seem to have caused definite plastic deformation of the test pieces.

O'Connor and Morrison[9] obtained no fatigue failures in pulsating compression in a 2½%Ni–Cr–Mo steel on testing at stresses up to that of the primitive yield, and obtained only buckling of their test pieces in certain cases at still higher stresses. Woodward *et al.*,[10] working on aluminium alloys, did obtain fatigue failures in pulsating compression but the maximum stresses applied were often well in excess of the 0·1% proof stress. Such applied stresses would be expected to cause significant plastic deformation, a point which the authors confirmed in the subsequent discussion[11, 12] of their results.

The objections to excessive plastic deformation occurring during the first few cycles of loading and fatigue test are twofold: (*a*) the material is now in a cold-worked condition and would contain extra lattice

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The work described was carried out at the Brown-Firth Research Laboratories. Dr Cina is now with the Commissariat à l'Energie Atomique Laboratoires, Rehovoth, Israel.

TABLE I Analyses of the alloys

Cast no.	Type	wt-% C	Si	Mn	S	P	Cr	Ni	N
HJ1304	13%Cr	0·21	0·47	0·53	0·013	0·026	13·08	0·29	0·025
01875	20%Cr	0·06	0·25	0·70	0·017	0·015	20·68	0·21	0·027
01876	20%Cr	0·06	0·25	0·73	0·017	0·016	20·76	0·21	0·025
08742	20%Cr	0·033	0·16	0·65	0·024	0·014	19·72	0·23	0·012
87165	NMC	0·62	0·35	7·32	0·005	0·026	3·86	8·55	0·021
69190	NMC	0·63	0·41	7·45	0·008	0·034	4·00	8·35	0·015

defects which might complicate any subsequent fatigue mechanism, and (*b*) an accurate knowledge of the stress applied in subsequent cycles may no longer be possible. While some plastic deformation is inevitable in the fatigue testing of certain metals and alloys, the purpose of the test can decide when such deformation has become excessive.

Ignoring cast irons for the moment because of the complication of the graphite flakes, the difficulties encountered with plastic deformation during so many of the other tests referred to and the paucity of the data seemed to justify further work in this field. Accordingly, the fatigue strength in pulsating tension, alternating tension–compression, fluctuating compression–tension (using a mean compressive stress) and pulsating compression was investigated in three alloy steels as follows.

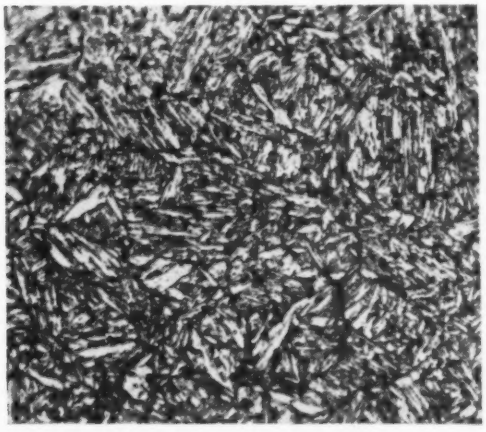
MATERIALS USED

The work was carried out on three alloy steels, one austenitic (hereafter referred to as NMC) and two ferritic. The latter were of the 13%Cr (martensitic) and 20%Cr (δ-ferritic) types. All the steels were obtained as $\frac{3}{4}$-in. dia. hot-rolled bar; the 13%Cr steel was obtained also as 22-mm dia. hot-rolled bar. The analyses of the steels are given in Table I.

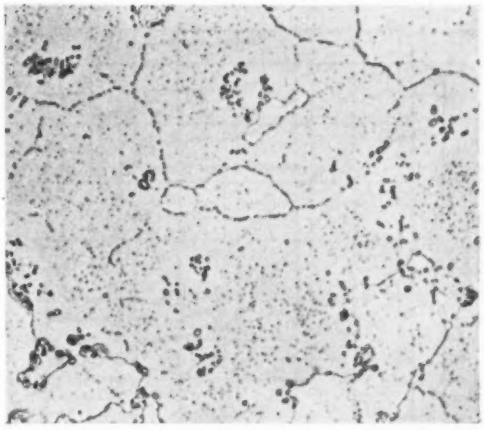
Details of heat-treatment and mechanical properties

The heat-treatments given to the three alloy steel types were as follows:

13%Cr steel	$\frac{1}{2}$ h at 1000°C OQ+1 h at 650°C WQ
20%Cr–Fe	2 h at 800°C WQ (casts 01875 and 01876)
	$\frac{1}{2}$ h at 830°C WQ (cast 08742)
Austenitic steel, NMC	$\frac{1}{2}$ h at 1050°C AC



1 *13%Cr steel; ½ h at 1000°C OQ + 1 h at 650°C WQ* ×500



2 *20%Cr–Fe; softened 2 h, 800°C WQ* ×500

The heat-treatment given to the 13%Cr steel resulted in a microstructure of tempered martensite, while that given to the 20%Cr–Fe resulted in a microstructure of chromium carbide particles in a matrix of polygonal δ-ferrite grains, these microstructures are shown in Figs.1 and 2, respectively.

The microstructure of the austenitic alloy steel consisted of twinned polygonal austenite grains with a very small amount of $(Cr, Fe)_{23}C_6$ precipitated at the grain boundaries (Fig.3).

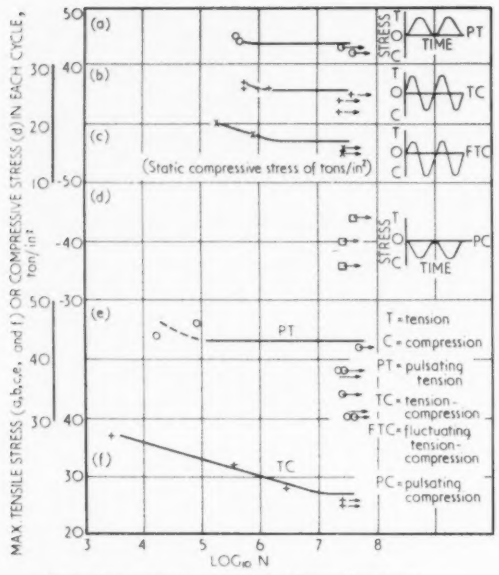
The 13%Cr steel was tested only in the above heat treated condition. The 20%Cr–Fe and the NMC alloy were tested in the above heat-treated conditions (i.e. softened) and also after various degrees of cold working. The 20%Cr–Fe was cold worked by drawing, and the NMC alloy by stretching, both processes being carried out at room temperature.

The mechanical properties obtained after these several heat-treatments and cold working operations are detailed in Table II.

DETAILS OF FATIGUE TESTING

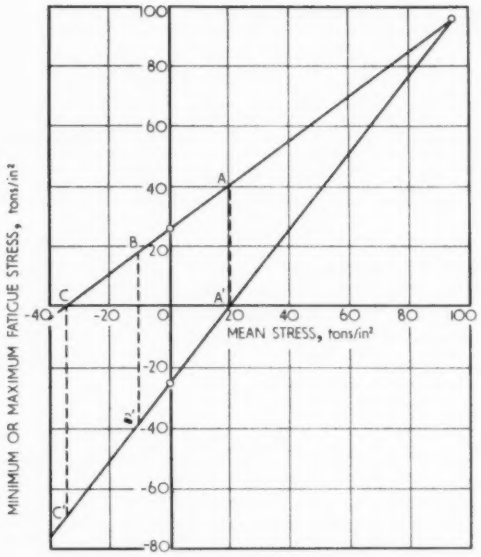
All the fatigue tests were carried out in direct stress on a Haigh machine operating at 6000 cycles/min. The fatigue test pieces had a gauge length roughly 0·178 in.

3 *NMC austenitic steel; softened ½ h, 1050°C AC* ×500



a Pulsating tension *b* Alternating stress
c Fluctuating stress *d* Pulsating compression
e and *f* ¾-in. dia. bar
e Pulsating tension *f* Alternating stress

4 *S/N curves and fatigue test results for the 13%Cr steel, cast HJ1304*



5 *Modified Goodman diagram for the 13%Cr steel, cast HJ1304, 22-mm dia. bar*

or 0·160 in. dia. × ½ in. long, or 0·140 in. dia. × ¼ in. long. They were mechanically abraded and finally electrolytically polished before testing as described previously.[13] An S/N curve was determined, where possible, for each mode of stressing, the fatigue limit being based on the test pieces remaining unbroken after 25×10^6 cycles. More attention was paid to determining the fatigue limit than the precise slope of the finite life section of the S/N curve.

Pulsating tensile or compressive stresses varied between O and the highest stress, S, required, and were obtained by applying a static stress, S/2, of half the maximum stress and superimposing on this an alternating stress of ±S/2. The fluctuating compressive–tensile stress cycle was obtained by superimposing an alternating stress on a static compressive stress of fixed value.

RESULTS

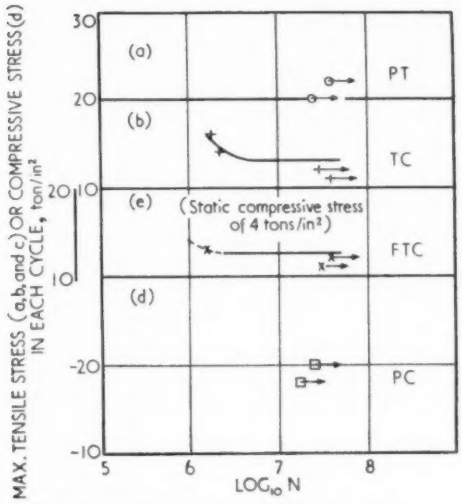
13%Cr steel

Fatigue tests were carried out in (*a*) pulsating tension, (*b*) alternating tension–compression, (*c*) fluctuating compression–tension (with a static compressive stress of 10 tons/in²), and (*d*) pulsating compression. The results are illustrated in Figs.4*a–d*. The fatigue limit for pulsating tension (from Fig.4*a*) is 0 to +43·5 tons/in² and for alternating tension–compression (Fig.4*b*) it is ±25·5 tons/in². The introduction of a compressive stress in the latter test has reduced the maximum repeated tensile stress which the material can withstand from 43·5 to 25·5 tons/in². By applying a static compressive stress of 10 tons/in² (Fig.4*c*) the maximum tensile stress which the material will withstand has been reduced to only 17 tons/in², although the material will now withstand a larger range of alternating stress (±27 tons/in²). Finally, for pulsating compression (Fig.4*d*) no fatigue failures at all could be

TABLE II Mechanical properties

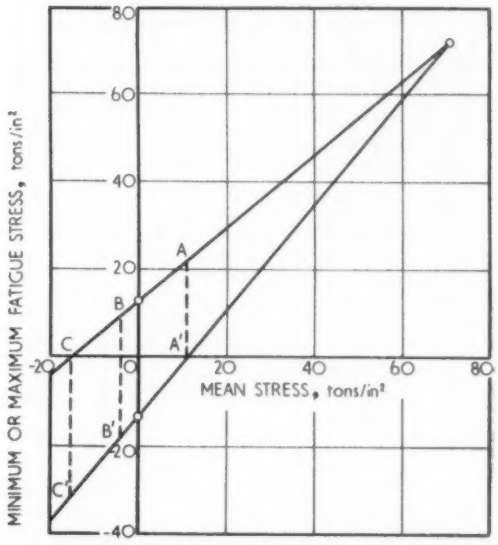
Alloy steel	Cast no.	Prior treatment	Limit of proportionality, tons/in²	Proof stress, tons/in² 0·05%	0·1%	0·2%	0·5%	Max. stress, tons/in²	True fracture stress, tons/in²	El., %	R. in A., %
13%Cr	HJ1304	As heat-treated*	22·1	36·5	38·6	40·8	42·7	54·2	95·0	27	66
20%Cr	01875	Softened	14·6	20·5	21·4	21·9	22·1	31·4	71·4	41	73
20%Cr	01876	Softened	10·0	18·1	18·9	19·8	19·9	30·7	71	43·5	76
20%Cr	01876	Cold drawn, 37·8%	5·0	26·0	36·3	41·8	43·4	43·4	72	20	61
20%Cr	01876	Cold drawn, 61·1%	7·0	33·0	42·2	45·5	46·0	46·6	75·7	19	61·5
20%Cr	08742	Softened	5·9	14·8	15·8	16·4	17·3	26·3	69·0	49·5	77·5
20%Cr	08742	Cold drawn, 20%	4·4	23·0	28·8	31·1	31·9	31·9	64·4	33·5	73
NMC	87165	Softened	14·6	20·7	21·3	21·8	22·6	52·0	152·5	89	72
NMC	87165	Stretched, 20%	10·9	36·5	45·0	49·7	49·7	61·5	140·0	55·5	65
NMC	87165	Stretched, 30%	21·7	53·3	59·6	60·4	60·4	68·0	148·5	43·5	64
NMC	69190	Softened	15·6	20·1	20·6	21·4	22·1	50·6	128·2	81	66·5
NMC	69190	Stretched, 43%	12·1	47·0	61·7	70·0	70·0	75·0	143·0	31	57

* 22-mm dia. bar



a Pulsating tension *b* Alternating stress
c Fluctuating stress *d* Pulsating compression

6 *S/N curves and fatigue test results for the 20%Cr–Fe, cast 01875, softened*



7 *Modified Goodman diagram for the 20%Cr–Fe, cast 01875, softened*

obtained up to a maximum compressive stress of 44 tons/in². An attempt to carry out a fatigue test at 0 to −48 tons/in² resulted only in buckling the sample after 5×10^6 cycles, due to plastic deformation. This sample, however, still had not cracked. Part of this work, in pulsating tension and alternating tension–compression, was repeated on a bar from the same cast, HJ1304, but rolled on a different occasion and to a slightly different size, $\frac{3}{4}$ in. dia. For the same heat treatment as previously, the mechanical properties obtained were as follows:

Limit of proportionality	Proof stress, tons/in² 0·05%	0·1%	0·5%	MS	El., %	R. in A., %
35·0	42·2	43·5	46·6	56·4	24	62

These properties are fairly similar to those given for the 22-mm dia. material in Table II.

The fatigue results for this $\frac{3}{4}$-in. dia. material are shown in Figs.4*e* and *f*. The fatigue limits in pulsating tension and alternating tension–compression are 0 to +43 tons/in² and ±27 tons/in² respectively, which are very close to those previously obtained on the 22-mm dia. bar, and therefore, confirm these results.

The use of a Goodman diagram with the 13%Cr steel

A modified Goodman diagram was constructed for the 13%Cr steel based simply on the fatigue limit in alternating stress and the true fracture stress of the material.

It was considered that for this purpose there was more justification for using the true instead of the more usual nominal fracture stress. Experience in these laboratories has shown that by using the true fracture stress value, better correlation with fatigue test results is obtained.

It was of interest, therefore, to see how the observed fatigue limits or results for pulsating tension, fluctuating tension–compression and pulsating compression compared with those predicted by a modified Goodman diagram. Such a diagram for the 22-mm dia. bar material is shown in Fig.5. This predicts the following results:

(i) a fatigue limit in pulsating tension of 0–40·5 tons/in² (*A A'* in the figure)
(ii) a fatigue limit in fluctuating tension–compression (for a static mean stress of 10 tons/in² in compression) of ±28 tons/in² (*B B'* in the figure), and
(iii) a fatigue limit in pulsating compression of 0 to −69 tons/in² (*C C'* in the figure).

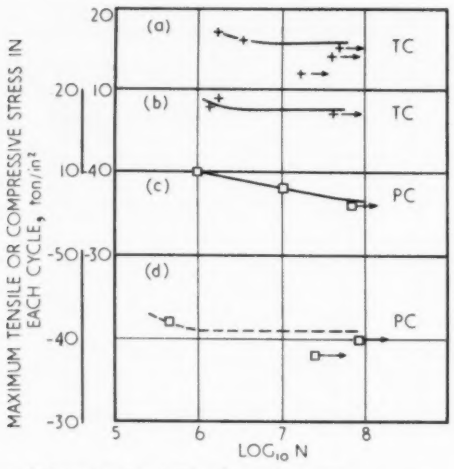
The experimentally determined values corresponding to (i) and (ii) were 0–43·5 tons/in² and ±27 tons/in²; the agreement is considered to be quite good.

Since the static 0·5% proof stress value of the material was 42·7 tons/in² the predicted fatigue limit in pulsating compression of 0 to −69 tons/in² implied that the requisite magnitude of fatigue stress could not be applied without excessive plastic deformation of the material during testing. However, it should have been possible to apply pulsating compressive fatigue stresses at least as high as the 0·5% proof stress value without failure; this was in fact found.

20%Cr–Fe, cast 01875

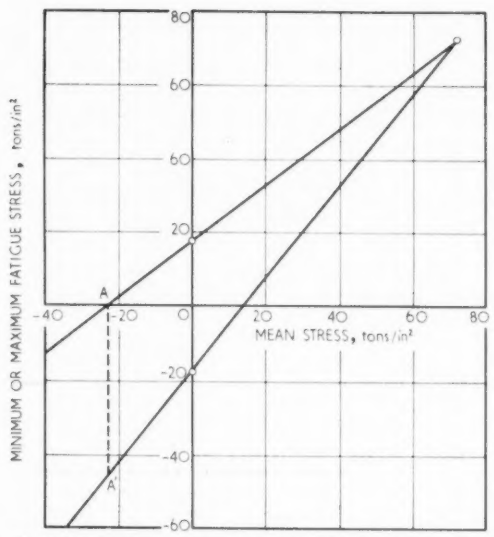
Fatigue tests were carried out in (*a*) pulsating tension, (*b*) alternating tension–compression, (*c*) fluctuating compression–tension, and (*d*) pulsating compression. The results are illustrated in Figs.6*a–d*. No fatigue failures were obtained in pulsating tension up to 22 tons/in². Tests were carried out at 0 to +24 and 0 to +26 tons/in² which each ran unbroken for 25×10^6 cycles, but as the 0·5% proof stress of the material was 22·1 tons/in², these tests are bound to have involved significant plastic deformation and, therefore, the actual applied stresses would have been other than intended.

The fatigue limits in alternating tension–compression and fluctuating tension–compression (with a static mean compressive stress of 4 tons/in²) were +1 and ±16·5 tons/in² respectively.



a Softened and tested in alternating stress
b Cold drawn 37·8% and tested in alternating stress
c Cold drawn 37·8% and tested in pulsating compression
d Cold drawn 61·1% and tested in pulsating compression

8 *S/N curves and fatigue test results for the 20%Cr–Fe, cast 01876*



9 *Modified Goodman diagram for the 20%Cr–Fe, cast 01876, cold drawn 37·8%*

No fatigue failures were obtained in pulsating compression at stresses up to 20 tons/in².

The use of the Goodman diagram with the 20%Cr–Fe cast 01875

A modified Goodman diagram for this material is shown in Fig.7. This predicted a fatigue limit in pulsating tension of 0 to 22 tons/in² (*A A'* in Fig.7). This value, however, is almost equal to that of the 0·5% proof stress so that it is perhaps not too surprising that no fatigue failures in pulsating tension were actually observed.

The Goodman diagram predicted a fatigue limit in fluctuating tension–compression (*B B'* in Fig.7) of ±13·5 tons/in². The experimentally determined value was ±16·5 tons/in².

Finally, the Goodman diagram predicted a fatigue limit in pulsating compression of 0 to −31·5 tons/in² (*C C'* in Fig.7). Since the 0·5% proof stress value was only 22·1 tons/in², no fatigue failure should have been obtained on testing at stresses at least as high as the 0·5% proof stress and none were, in fact, observed. Fatigue testing in compression at stresses higher than this were clearly impracticable.

20%Cr–Fe, cast 01876

The Goodman diagram for the 20%Cr iron, cast 01875, had indicated that if a fatigue limit in pulsating compression were ever to be observed, the material would have to be cold worked to be able to withstand the requisite stresses. No further material being available from cast 01875, the work was continued on cast 01876 of similar chemical composition and mechanical properties. Fatigue tests in pulsating compression carried out on cast 01876 in the softened condition at stresses of 0 to −18 tons/in² and 0 to −20 tons/in² remained unbroken after 50×10^6 and 35×10^6 cycles respectively, confirming the corresponding results on cast 01875. The fatigue limit in alternating tension–compression for cast 01876 in the softened condition was ±15·5 tons/in² (Fig.8*a*). Some of the bar material from cast 01876 was cold drawn in the softened condition from 0·763–0·650 in. dia., i.e. by 37·8% true reduction in area,* the mechanical properties being given in Table II. The fatigue limit in alternating tension–compression for the 37·8% cold-drawn condition was ±17·5 tons/in² (Fig.8*b*). The fatigue strength of the material has benefited only slightly as a result of cold drawing. A Goodman diagram for the 37·8% cold-drawn material is shown in Fig.9. This predicts a fatigue limit in pulsating compression at 0 to −46 tons/in² (*A A'* in Fig.9). Although this value is somewhat greater than the static 0·5% proof stress value of the material, fatigue tests were carried out and the results are given in Fig.8*c*. This indicates that definite fatigue failures were obtained at 0 to −40 tons/in² and 0 to −38 tons/in². A sample tested at 0 to −36 tons/in² remained unbroken after 70×10^6 cycles; the slope of the curve suggests that failure may have been obtained had the test been continued. The fatigue limit based on 25×10^6 cycles for this 37·8% cold-drawn material was 0 to $-37\frac{1}{2}$ tons/in².

However, as this fatigue limit in pulsating compression may have depended on the fortuitous amount of cold drawing applied to the bar, it was of interest to know whether material cold drawn further would give a higher fatigue limit in pulsating compression. Accordingly, the bar cold drawn by 37·8% was further drawn from 0·650 in. to 0·601 in. dia., this representing a total true reduction in area (compared with the original diameter of 0·763 in.) of 61·1%. The mechanical properties obtained are given in Table II. The 0·5% proof stress value has now been raised to 46 tons/in² compared with 43·4 tons/in² for 37·8% cold work. The material clearly has limited work hardening capacity.

The results of fatigue tests carried out on this 61·1% cold-drawn bar are shown in Fig.8*d*. This shows that while a definite fatigue failure was obtained at 0 to

* True reduction in area, $\% = \dfrac{\text{original area} - \text{final area}}{\text{final area}} \times 100$

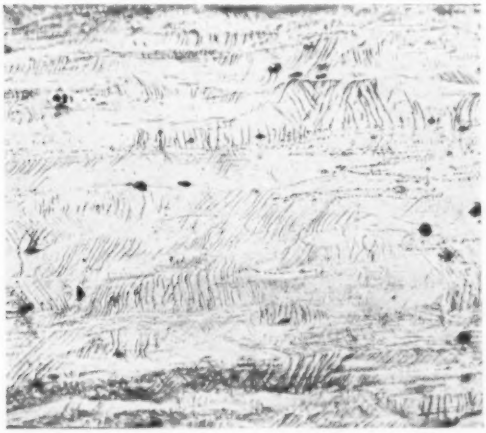
10 *20%Cr–Fe, cast 01876, cold drawn 61·1%, 10^5 cycles at 0 to −42 tons/in²* ×100

−42 tons/in², samples tested at 0 to −40 tons/in² and 0 to −38 tons/in² remained unbroken after 82 and 25×10^6 cycles respectively. The extra cold drawing has clearly increased the compressive fatigue strength from about 0 to −37½ tons/in² to 0 to −41 tons/in².

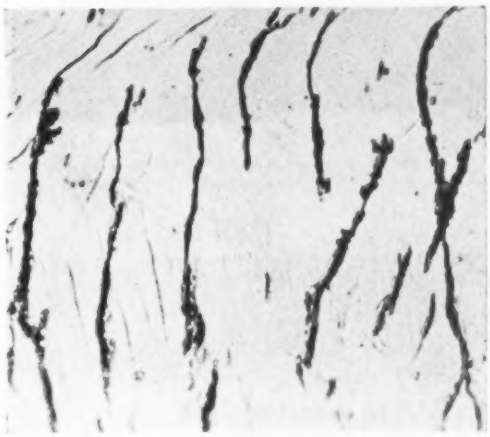
As cold working had only a limited beneficial effect on the fatigue limit in reversed direct stress of the 20%Cr–Fe, the lines of the Goodman diagram for the bar cold drawn 61·1% would have lain very close to those for the bar cold drawn only 37·8%, and would, therefore, have predicted a fatigue limit in pulsating compression not much greater than that predicted for the 37·8% cold drawn bar (0 to −46 tons/in²). The experimentally determined value of 0 to −41 tons/in² for the 61·1% cold drawn bar supports this prediction.

Mechanical properties in static compression

As it was realized that due to the Bauschinger effect, the same proof stress values might not be obtained when cold-worked material was tested in tension as in compression, compressive fatigue stresses would be better compared with static compressive proof stresses than with static tensile ones. Accordingly, the static compressive proof stresses were determined on the



11 *As Fig.10 but after 2×10^5 cycles* ×100



12 *As Fig.11* ×250

20%Cr–Fe bar cold drawn 61·1%. This was done by compressing a cylinder of the material under constant increments of load and measuring the change in diameter produced on unloading after each load increment. The results, together with those obtained in tension, are given below:

Mode of testing	LP tons/in²	Proof stress, tons/in² 0·05%	0·1%	0·2%	0·5%
Tension	7·0	33·0	42·2	45·5	46·0
Compression	8·4	...	22·5	31·2	37·4

These figures indicate the operation of a definite Bauschinger effect. Since the stresses applied in the pulsating compression fatigue tests were greater than the static compressive 0·5% proof stress value, the corresponding strains involved in the fatigue tests were obtained from the compressive stress-strain data. The results were as follows:

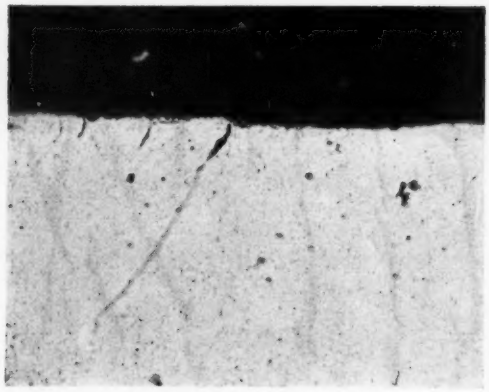
Compressive stress, tons/in²	38	40	42
Plastic compressive strain, %	0·535	0·88	1·48

As proof and yield stress values are known to be greater the faster the rate of stressing, the actual plastic strains involved in the compressive fatigue tests were probably less than those given above. Their effect, however, would be somewhat to alter the applied fatigue stress after the first few cycles, probably by making the alternating stress system superimposed on the static compressive one unsymmetrical. The full stress cycle would then vary from $-x$ to $-y$ tons/in² instead of from 0 to $-S$ tons/in².

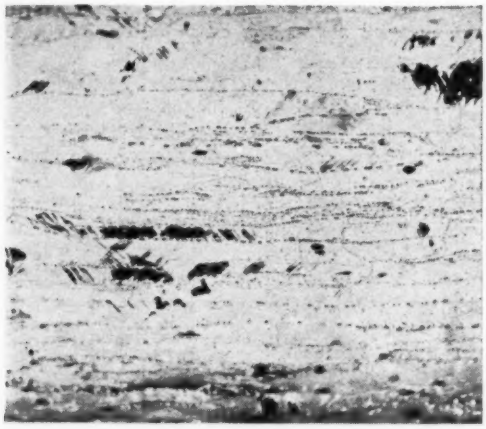
Metallographic aspects of pulsating compression fatigue tests

Since definite fatigue failures were obtained on stressing in pulsating compression, it was of considerable interest to study the metallographic changes accompanying these failures and also those obtaining at interrupted stages before failure. Such changes might indicate possible fatigue mechanisms.

In the unfatigued condition, the microstructure of the as-cold drawn 20%Cr–Fe steel samples consisted simply of elongated ferrite grains outlined by undissolved chromium carbide particles. The application of pulsating compressive stresses of the order of the static proof stresses resulted in the appearance of slip lines and other effects, the latter appearing similar to the

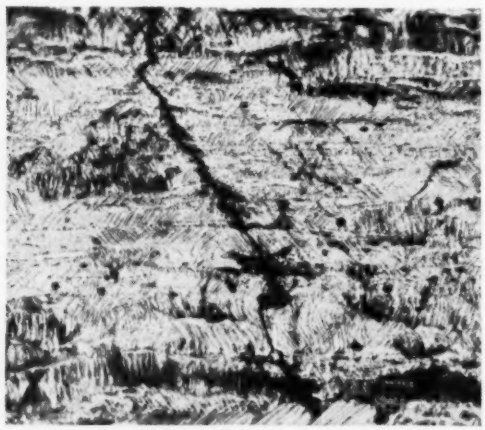


13 *As Fig.10 but after 3×10^5 cycles* ×500

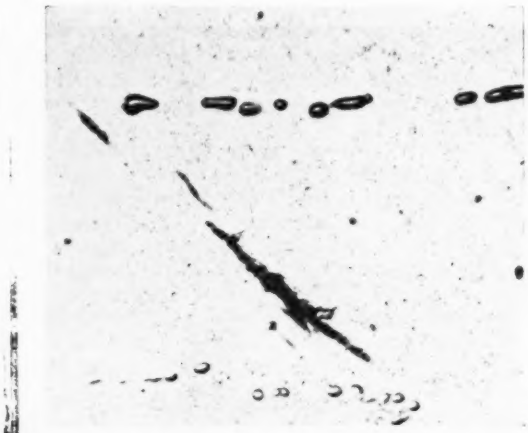


15 *Steel as Fig.10 but after 82×10^6 cycles at 0 to −40 tons/in²* ×100

extrusion and intrusion effects observed by Forsythe in aluminium[14] and other non-ferrous base[15] alloys. Figures 10 and 11 illustrate the increasing number and intensity of all three effects in samples of the 61·1% cold-drawn bar interrupted after stressing for 10^5 and 2×10^5 cycles respectively at 0 to −42 tons/in². Figure 12 shows the dark intrusions and associated thin white extrusions, all of which seem to have formed on the slip lines of wavy form characteristic for body-centred cubic metals. Although very common throughout the sample, the intrusion and extrusion effects were not visible in every grain; slip lines were more common. After 3×10^5 cycles, a sample tested at the same stress as the aforementioned showed even more intensely the three-fold effects mentioned above. Since it has been suggested that, for samples tested in alternating tension–compression and showing extrusion effects, fatigue cracks are nucleated at the intrusions, it was of interest to section some of the above samples tested in pulsating compression. A longitudinal section taken through the gauge length of the sample run for 3×10^5 cycles at 0 to −42 tons/in² revealed very many fine cracks originating at the surface. At least six such cracks are illustrated in Fig.13. They all tended to run at about 45° to the principal axis of the test piece and sometimes were seen to originate from hollows on the surface, these hollows possibly being intrusions. The relative distribution of these cracks in the section was in keeping with that of the intrusions on the surface. The fatigue failure in a 61·1% cold-drawn sample tested at 0 to −42 tons/in² was accompanied by several large secondary cracks on the gauge length of the sample. One such crack in a background of slip, extrusion, and intrusion effects is illustrated in Fig. 14. In connexion with the many secondary cracks observed on the gauge length of the sample tested to failure at 0 to −42 tons/in², it is of interest that Woodward *et al.*[10] also observed a multitude of cracks in their aluminium alloys tested at large pulsating compressive stresses. In the present work, slip lines, intrusions, and extrusions were observed even in samples which had remained unbroken after many millions of cycles. The effect of decreasing the maximum compressive stress was initially to decrease the total number of extrusions, slip lines, etc, but to cause these to appear in more concentrated form as in Fig.15 which illustrates the gauge length of some 61·1% cold-drawn material stressed without failure for 82×10^6 cycles at 0 to −40 tons/in². Figure 16



14 *As Fig.10 but after failure at $4{\cdot}5 \times 10^5$ cycles* ×100



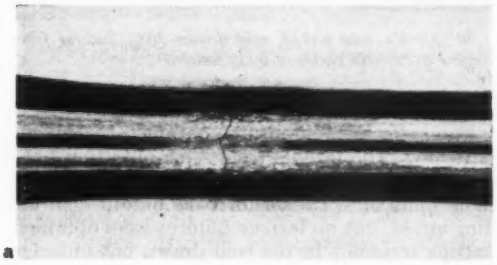
16 *Steel as Fig.10 but after 25×10^6 cycles at 0 to −38 tons/in²* ×1250

shows the isolated character of the slip lines, extrusions, and intrusions observed on reducing the maximum stress still further to 0 to −38 tons/in².

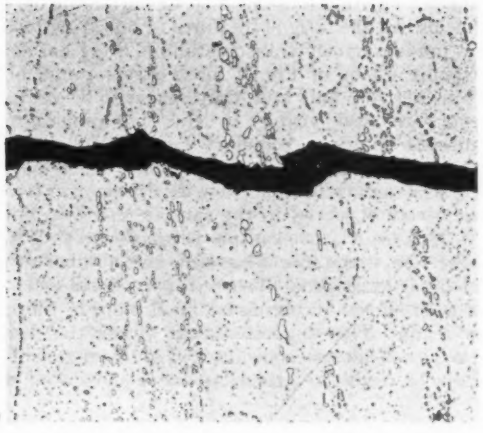
Features similar to those described above were also observed in the 20%Cr–Fe material cold drawn only 37·8%. Figure 17*a* shows the gauge length of the sample tested to failure at 0 to −40 tons/in². A very large crack extending well round the sample is clearly visible. The gauge length also shows signs of plastic deformation. A longitudinal section taken through the fractured gauge length showed the main crack to be transcrystalline. Various lengths of the crack, however, did not follow straight paths across the grains but often curved ones, presumably in keeping with the wavy slip line pattern in the material. Figures 17*b* and 17*c* show longitudinal sections through the main crack

17 *20%Cr–Fe, cast 01876, cold drawn 37·8%, failure at 9·98 × 10⁵ cycles at 0 to −40 tons/in²*

(*a*) × 5
(*b*) × 500
(*c*) × 500
(*d*) × 100
(*e*) × 500
(*f*) × 500


a

d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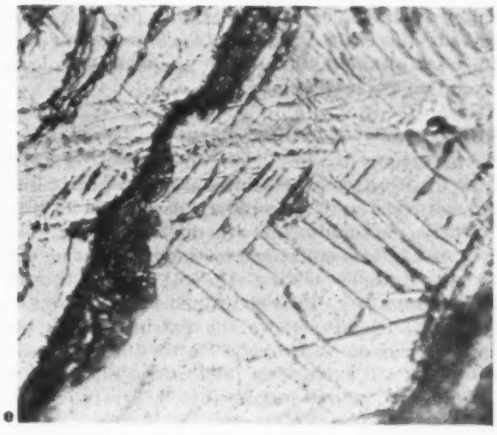
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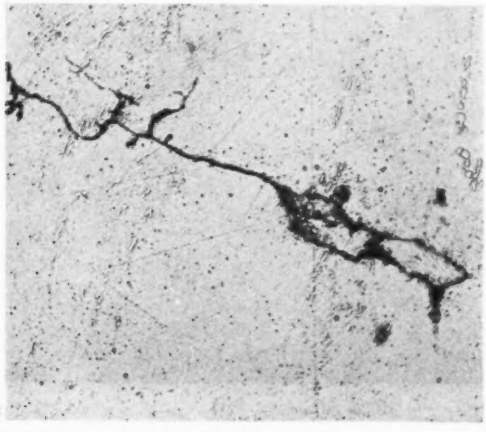
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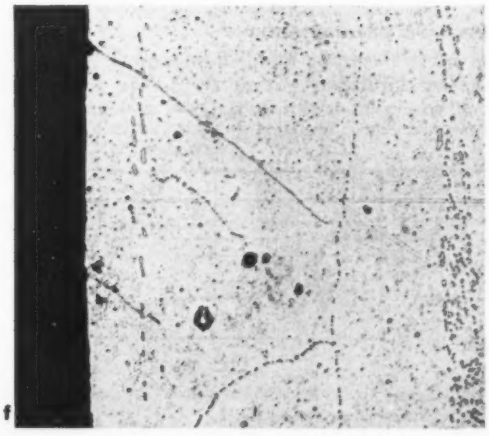
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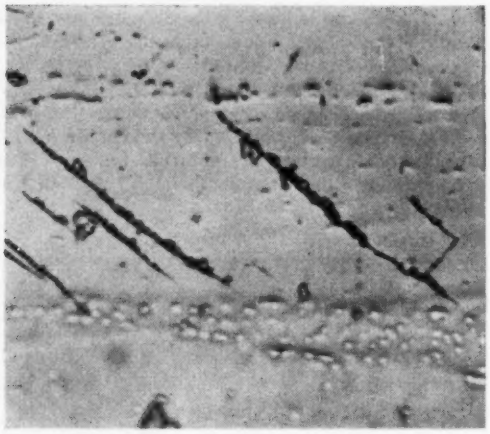
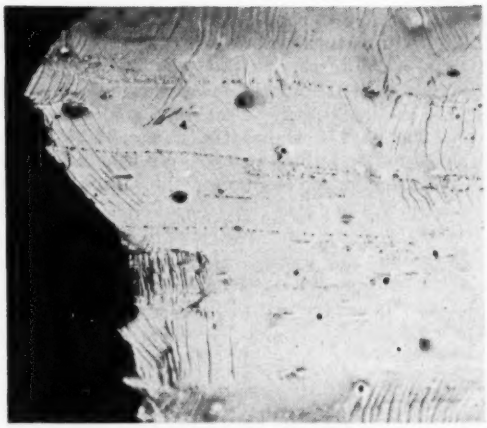


18 *20%Cr–Fe, cast 01876, cold drawn 61·1%, 10^5 cycles at ± 20 tons/in²* ×1000



20 *20%Cr–Fe, cast 08742, cold drawn 20%, fatigue fracture after $4{\cdot}19 \times 10^5$ cycles at 0–32 tons/in²* ×100

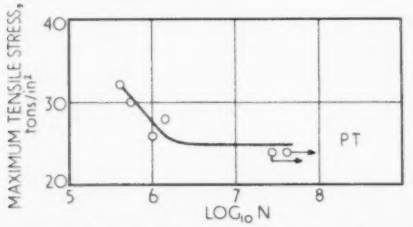
at points near its origin (Fig.17*b*) and at its end (top left-hand corner of Fig.17*c*). Figure 17*d* shows secondary cracks in a background of slip lines, extrusions, and intrusions observed on the gauge length. Figure 17*e* shows, at a higher magnification, some pronounced extrusion effects, especially towards the left-hand side; a large intrusion can also be seen associated with the broadest extrusion. Finally, Fig.17*f* shows two particularly clear examples of fine cracks observed in the longitudinal section of this sample. These cracks, as in Fig.13, run at about 45° to the principal axis and seem to originate at possible intrusions.

Extrusions in alternating stress

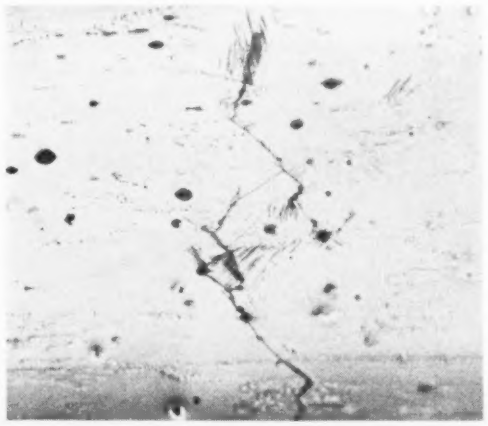
Since extrusions had first been reported[14] after fatigue testing in alternating stress, it was of interest to know whether they would be so obtained in the cold-drawn 20%Cr–Fe, especially since this material had already shown such effects on fatigue testing in pulsating compression. Fatigue testing the 61·1% cold-drawn material from cast 01876 confirmed that this was the case, Fig.18 clearly shows the extrusions observed after 10^5 cycles at ± 20 tons/in². After $5{\cdot}3 \times 10^5$ cycles, the number of extrusions (and intrusions) had increased and some had increased in length by a factor of up to about three. This sample failed after $7{\cdot}98 \times 10^5$ cycles.

Extrusions in pulsating tension

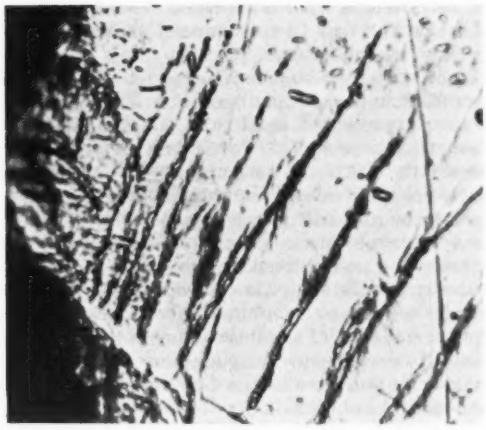
It is worth recording the metallographic observations made on a further cast of 20%Cr–Fe (cast 08742) which was cold drawn 20%, gave a definite fatigue limit on testing in pulsating tension, and showed that extrusion effects could also be obtained by this mode of stressing. The fatigue results for pulsating tension are given in Fig.19. (In the softened condition, a fatigue limit of ± 13 tons/in² was obtained in alternating stress, but no fatigue failures were obtained in pulsating tension.) In the cold drawn but unfatigued condition the microstructure consisted of structureless elongated ferrite grains outlined by chromium carbide particles. All the fatigue fractures in pulsating tension were predominantly transcrystalline, a typical example being given in Fig.20 for a stress range of 0–32 tons/in². Slip lines and what appear to be extrusion effects are also visible in this photomicrograph. Figure 21 shows a secondary transcrystalline crack with associated slip and extrusion effects observed on the gauge length. Some particularly clear extrusion effects were observed in the sample tested to failure at 0–30 tons/in², an example being shown in Fig.22. As the test stress was decreased, the number of slip lines and extrusions observed also decreased, the extrusion effects becoming confined more to the fracture region. This suggested that either the fatigue process itself became concentrated in this region of the sample or that the extrusions were associated with



19 *S/N curves for the 20%Cr–Fe, cast 08742, cold drawn 20%, fatigue tests in pulsating tension*



21 *As Fig.20, gauge length* ×100

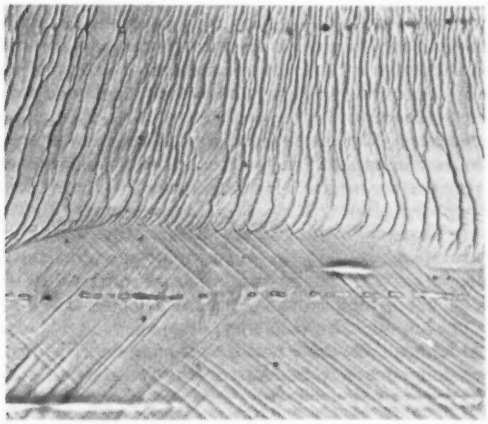


22 *Steel as Fig.20 but after $5{\cdot}77 \times 10^5$ cycles at 0–30 tons/in² × 1500*

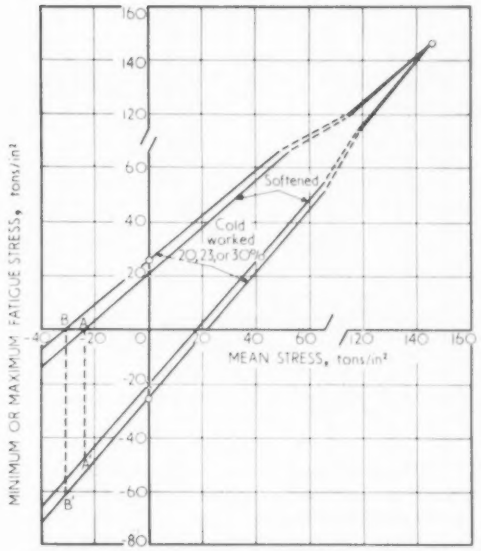
possible plastic deformation accompanying the failure of the sample. To test the latter hypothesis, some non-fatigue tested material was deformed in tension by $1\frac{1}{2}\%$, $4\frac{1}{2}\%$, $8\frac{1}{2}\%$, and up to fracture and examined after each stage. Only slip lines were observed at each stage, a typical example being shown in Fig.23. It would seem then that the extrusions observed in the pulsating tension fatigue test pieces were caused by the fatigue process itself. It is of interest that neither slip lines nor extrusion effects were observed at a stress of 0–24 tons/in², i.e. below the fatigue limit, and just above the static 0·05% proof stress.

NMC alloy, cast 89165

The results of fatigue tests in pulsating tension and alternating tension–compression carried out on this alloy in the softened and cold-worked conditions have already been published.[13] It was there found that fatigue failures in pulsating tension could be obtained only after the alloy had been statically cold worked by 10% or over. In the present work, fatigue tests were carried out only in pulsating compression. The Goodman diagram for the softened condition ($\frac{1}{2}$ h at 1050°C AC), shown in Fig.24, predicts a fatigue limit in



23 *Steel as Fig.20, gauge length after $4\frac{1}{2}\%$ stretch* ×500

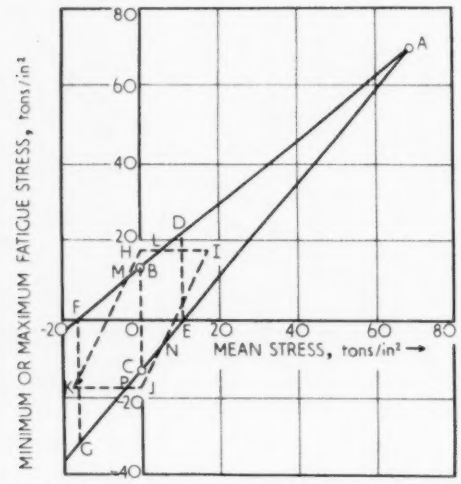


24 *Modified Goodman diagrams for NMC austenitic steel, softened ½ h at 1050°C AC, and cold worked 20, 23, and 30% in tension*

pulsating compression of 0 to −48 tons/in² (AA' in Fig.24). As this is considerably in excess of the 0·5% proof stress value (22·6 tons/in²) no fatigue failures should be obtained on testing at stresses up to the latter value, and no fatigue failure was, in fact, obtained at 0 to −22, −20, or −18 tons/in² after 195, 42, or 84×10^6 cycles, respectively. As with the 20%Cr–Fe, the Goodman diagram for NMC implied that the material would have to be cold worked to withstand the required stresses in pulsating compression. Suitable tensile test pieces were stretched 20, 23, and 30% and Haigh fatigue test pieces were machined from the stretched gauge lengths. Such amounts of cold work gave 0·5% proof stress values (in tension) of about 50, 53, and 60 tons/in² respectively. While such cold-worked material could now probably withstand the maximum compressive stress of 48 tons/in² previously predicted, the Goodman diagram from which this value was derived would no longer be applicable. Figure 24 also shows the new Goodman diagram for 20, 23, or 30% cold-worked material. (The one diagram serves for all three amounts of cold work since previous work[13] had shown that the fatigue limit in reversed direct stress did not increase on increasing the amount of cold work from 20–30%.) This predicts a fatigue

TABLE III Fatigue results in pulsating compression on the NMC alloy steel

Static cold work, %	0·5% proof stress, tons/in²	Fatigue stress, tons/in²	Life, cycles × 10^6, unbroken
0	22·6	0 to −18	84
0	22·6	0 to −20	42
0	22·6	0 to −22	195
20	49·7	0 to −48	24
20	49·7	0 to −50	25
23	53	0 to −48	25
23	53	0 to −50	25
23	53	0 to −52	40
30	60·4	0 to −50	25
30	60·4	0 to −54	57



25 *Modified Goodman diagram for the 20%Cr–Fe, cast 08742. ½ h at 830°C WQ*

limit in pulsating compression of 0 to −61 tons/in² (*B B'* in Fig.24). No fatigue failures should then be obtained on the 20 or 23% cold-worked material and probably none also on that cold-worked 30% because the predicted value is now still greater than the 0·5% proof stress; no failures were in fact obtained. The results are given in Table III.

In addition to the tests detailed in Table III, the 30% cold-worked material was tested at 0 to −58 and 0 to −56 tons/in², but both tests buckled on loading. This may have been due to some non-axiality in the test, but more probably was due to plastic deformation resulting from the high stresses applied. The extent of such deformation would be greater than that indicated by the tensile proof stresses of the material on account of the operation of a Bauschinger effect by applying a compressive stress to a sample previously cold worked in tension.

Since a Losenhausen fatigue testing machine of 6-tons load capacity had become available after this work was commenced, it became possible to carry out tests at greater maximum compressive stresses than was the case on the Haigh machine. Accordingly, as some 1¼-in. dia. bar of NMC steel was available from cast 69190, this bar was softened, cold worked 43% in tension to a 0·5% PS of about 70 tons/in² and tested at 0 to −64, −58, and −56 tons/in² respectively. The test pieces employed had gauge lengths and diameters of ½ in. and ¼ in. respectively. Every sample tested buckled on, or shortly after, reaching maximum stress.

It would seem that, at least for the various extents of cold work applied in tension, no fatigue failure in pulsating compression can be obtained in the austenitic alloy steel, NMC.

It would clearly have been of interest to have carried out fatigue tests in pulsating compression on NMC material prior cold worked statically in compression. A calculation, however, of the stress required to do this on a block of the material uniformly and safely showed the operation to be impracticable.

The usefulness of a modified Goodman diagram

It may be of interest to summarize what information can be obtained from a modified Goodman diagram (based on the true fracture stress) and to indicate a few other useful features.

Figure 25 shows such a diagram for the 20%Cr–Fe cast 08742, in the softened condition. The true fracture stress is represented at *A*, and the fatigue limit in alternating stress by *BC*. The magnitude of the fatigue stresses to which the material can be subjected is clearly limited if excessive plastic deformation on loading is to be avoided. If this limit is arbitrarily set at the 0·5% proof stress (in the absence of a sharply defined yield point), then a parallelogram *HIJK* can be drawn on the diagram indicating the permissible area in which any combination of stresses can be applied; *OH* and *HI* equal the value of the 0·5% proof stress. However, since fatigue failure can occur only outside the two lines of the Goodman diagram, such failures can be obtained only at stresses within the two small triangles *HLM* and *NJP*. Tests carried out at stresses within the remaining area *MLINPK* of the parallelogram will run without failure.

The diagram also shows the predicted fatigue limits in pulsating tension and pulsating compression, *DE* and *FG* respectively, and suggests that, since these stresses extend well beyond the permitted parallelogram *HIJK*, no fatigue failure should be obtained in simply pulsating tensile or compressive stress.

DISCUSSION

Perhaps the two most important observations made in the present work are (*a*) the finding of fatigue failures in simple pulsating compression tests, albeit in only one of the three steels tested, and (*b*) the association of these failures with intrusion and extrusion effects. Cottrell and Hull[16] have offered a theoretical explanation for the formation of intrusion and extrusion effects in copper and other non-ferrous metals,[17,14,15] fatigue tested in alternating stress. In the present work, the effects were observed after fatigue testing not only in alternating stress but also in simple pulsating tension and in simple pulsating compression. The question then arises as to whether a similar extrusion mechanism operates in all three cases. For this to be so, it would be necessary to postulate the introduction of a tensile stress during the unloading part of each cycle in the pulsating compression test, and the introduction of a compressive stress during the unloading part of each cycle in the pulsating tensile test. Such conditions may well obtain. Since evidence of plastic deformation (slip lines) was detected in samples which had failed by both modes of pulsating stress, stresses of sign opposite to that applied would be developed on each unloading half-cycle as in the Bauschinger mechanism. Fatigue failure in pulsating stress would then be dependent on plastic deformation occurring during the test and should be initiated in the region of active slip planes. It was in fact observed that (*a*) where there were no or only a few slip lines visible after fatigue testing in pulsating stress, no fatigue failures were obtained, and (*b*) the extrusions and intrusions formed on the slip planes. These two observations support the above hypothesis.

An alternative explanation is that the extrusion and intrusion effects were caused simply on the loading half-cycles of the pulsating tests in a manner similar to that described by Calnan and Williams.[18] These workers observed extrusion effects in an electro-

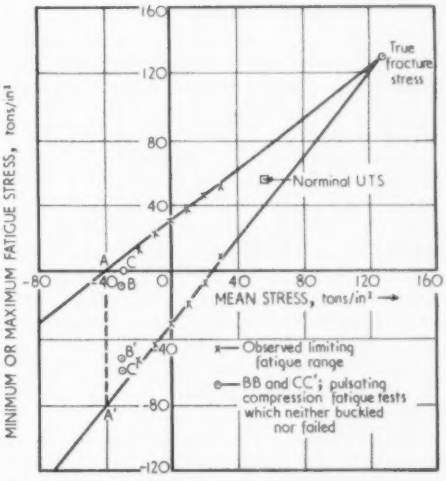
polished copper test piece after a single extension of 5·3% in straightforward tensile deformation. They suggested that the extrusion may have been caused by mixed slip which they defined as slip on parallel planes but in different <110> directions. If extrusion can occur in a single tensile cycle, it is not unreasonable to expect an even greater effect in a sample subjected to pulsating tensile cycles, even if the extent of extrusion in each of the pulsating tensile cycles is very much less than that got by the 5·3% extension in copper. Since there were definite signs of plastic deformation in those samples which failed in pulsating tension fatigue tests, one essential condition for extrusion is satisfied. A possible argument against this theory, however, is the fact that no extrusion effects were observed in the samples stretched once by various amounts in simple tension. This, however, may have been due to the relatively low magnification (×500) at which these samples were examined. Calnan and Williams[18] observed their extrusion effects at a magnification of ×10000.

If Calnan and Williams,[18] mixed slip mechanism operates in pulsating tension, presumably it will do so also in pulsating compression. While this might explain the formation of extrusions in pulsating compression, it would not explain why a fatigue crack should grow in such a test. The observed depths of such cracks are too great to be accounted for by the accumulation of voids accompanying an extrusion. This would mean that for pulsating compression, there was one mechanism to nucleate a crack (intrusion) and another mechanism to propagate it. For pulsating tension, crack propagation would be aided by the stress concentration factor at the tip of the crack. The actual mechanism of crack propagation in pulsating tension may be dependent on work hardening at the tip of the crack until the fracture stress is attained as suggested by Head.[19]

One further mechanism suggests itself. It will be recalled that the fatigue cracks which nucleated at the intrusions in the pulsating compression fatigue tests, all tended to lie at 45° to the principal axis of the test piece. This might imply that at least the propagation of these cracks was due to a shear component of the applied compressive stress.

The present work has confirmed that a higher fatigue limit obtains in pulsating tension than in alternating tension–compression, and that as the magnitude of the stress in the compressive cycle increases, that of the tensile stress which the material can withstand becomes smaller. However, since this tensile stress need be of only a relatively low value, provided the compressive cycle is large enough, the results suggest that a fatigue-damaged region or crack may be propagated initially not by having present a local tensile stress of the order of the fracture stress of the material as suggested by Head,[19] but simply by the joint action of alternate compressive and tensile cycles. The mechanism of this joint action might be one of local plastic deformation within the grains aided by the operation of a Bauschinger effect so that in the tensile cycle the actual local tensile stress attained may well be much greater than the nominal applied one. Although the latter might be low, the correspondingly large alternate compressive cycle would ensure large residual tensile stresses.

Thus, it becomes possible to visualize the propagation of a fatigue-damaged region by the local plastic deformation derived from the Bauschinger effect. It was previously found[13] that an austenitic alloy steel, 'damaged' by fatigue stressing in reversed direct stress for 10% of its expected life, had its life extended by a factor of 100–200 by subsequent fatigue stressing in pulsating tension at a stress equal to that used previously in the first 10% of its life in alternating tension–compression, i.e. a fatigue-damaged region could be propagated more readily by alternating tensile and compressive stresses than by a pulsating tensile stress of the same magnitude.



26 *Modified Goodman diagram for 2¼%Ni–Cr–Mo steel from results obtained by O'Connor and Morrison*[9]

Finally, a word might be said about the use of a Goodman diagram modified by basing it on the true and not the more usual nominal maximum stress. Since there was a fair degree of correlation between the predicted and observed pulsating and fluctuating stress fatigue limits, it was of interest to apply such a diagram to results obtained by others. The very careful and painstaking results obtained by O'Connor and Morrison[9] seemed an obvious choice. A Goodman diagram was constructed based on the true fracture stress and the fatigue limit in alternating stress (zero mean stress) as illustrated in Fig.26. The observed limiting fatigue ranges for static mean stresses of +30, +20, +10, −10, and −20 tons/in² fell almost exactly on the two lines of the diagram. Extrapolation of the two lines of the diagram predicted a fatigue limit in pulsating compression of 0 to −80 tons/in², (*A A'* in Fig.26) which, it is suggested, would explain why in fact no fatigue failures in compression were obtained on testing at stresses up to that of the yield point of the material, 50·4 tons/in². The excellent agreement between predicted and observed results, so obtained, provides further confirmation of the possible value of a Goodman diagram modified as above.

The nominal UTS of the material is also indicated in Fig.26. It will be seen that a linear (Goodman) relationship could not be drawn between the several fatigue test results and the nominal UTS value. Since the former do lie in linear relationship to one another, a parabolic (Gerber) relationship between them and the nominal UTS value would also be inapplicable.

SUMMARY AND CONCLUSIONS

1. The present work on a 13%Cr steel, a 20%Cr–Fe and an austenitic alloy steel has confirmed that a higher fatigue limit obtains in pulsating tension than in alternating tension–compression.

2. With a mean compressive stress, both ferritic materials withstood a lower tensile stress in the alternating stress cycle than was the case for zero mean stress.

3. For the 13%Cr and austenitic alloy steels, no fatigue failures could be obtained in pulsating compression at stresses up to the 0·5% proof stress, even when, as for the austenitic alloy steel, the 0·5% proof stress was materially increased by cold working.

4. Fatigue failures in pulsating compression were obtained in the 20%Cr–Fe, but only when the alloy had previously been adequately cold worked (by drawing).

5. Fatigue failures in pulsating tension, pulsating compression, and alternating stress were accompanied by extrusion and intrusion effects as found by Forsythe.[14, 15] These effects were observed on active slip planes.

6. In pulsating compression tests, the intrusions appeared to serve as crack nuclei. These cracks, initially, at least, formed at 45° to the principal stress axis and eventually spread across the sample.

7. Several possible fatigue mechanisms in explanation of the above observations are discussed.

8. For the several modes of stressing investigated, a fair degree of agreement was attained between the fatigue strengths observed and those predicted by Goodman diagrams, the latter modified by basing them on the true fracture stress of the material.

9. Further fatigue tests might profitably be carried out in pulsating tension or compression, since this allows better comparison with static tensile or compressive behaviour and also eliminates the complication of the Bauschinger effect on stress reversal.

ACKNOWLEDGMENTS

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An interesting example of early technology

A SOCKETED AXE FROM WIETRZNO-BOBRKA IN THE CARPATHIANS

J. Piaskowski

SYNOPSIS

Metallographic examination of an axe found at Wietrzno-Bobrka shows that it was made by welding two metals, an irregularly carburized soft steel and high-nickel iron. The ability to distinguish between different iron alloys indicates the high degree of knowledge attained by iron-workers in the VIII–IV centuries BC. 1722

SINCE 1955 the department of history and science and engineering of the Polish Academy of Science has been carrying out systematic metallographic examinations of ancient iron articles found in Poland.[1] One of the most interesting specimens examined was a small axe with a socketed head belonging to the Hallstatt period (VIII–IV centuries BC) found at the site of Wietrzno-Bobrka, near the Dukielska pass in the Carpathians, where archaeological investigations have been in progress since 1951 under the supervision of Dr A. Zaki.[2]

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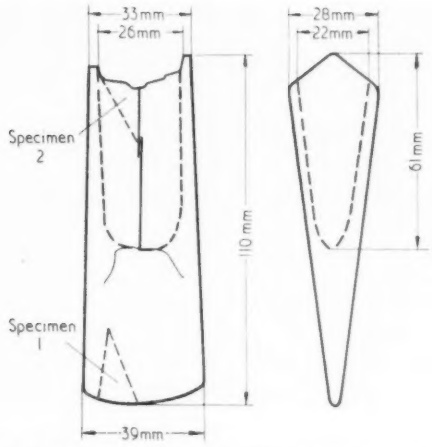
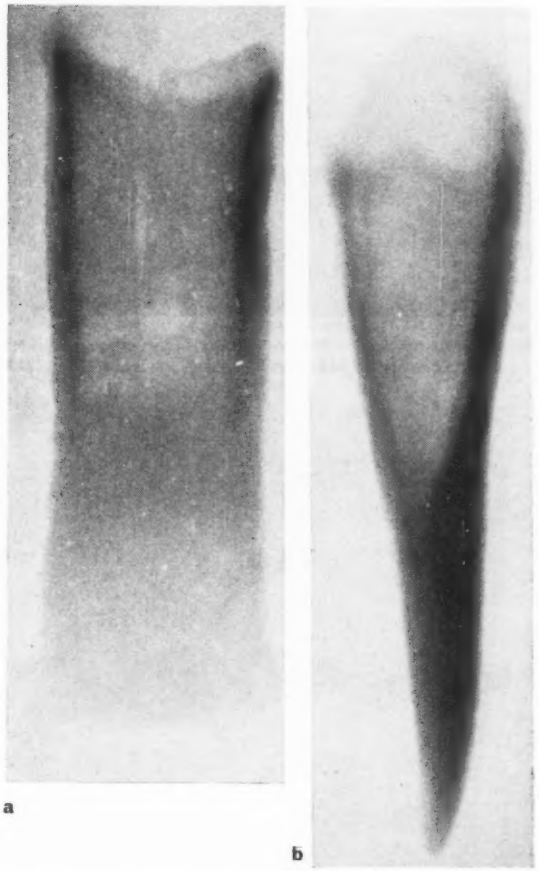


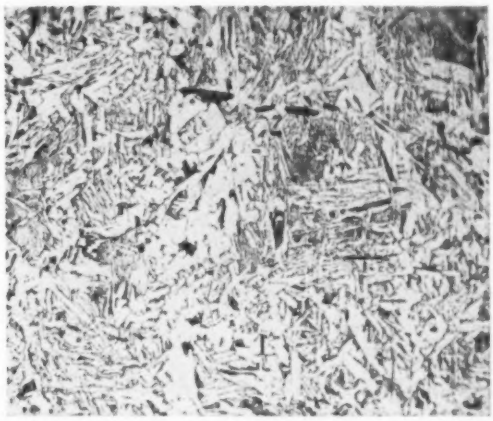
1 *Sketch of axe showing position of metallographic specimens*

3 *Macrostructure of specimen 1, etched in nital* ×6·5

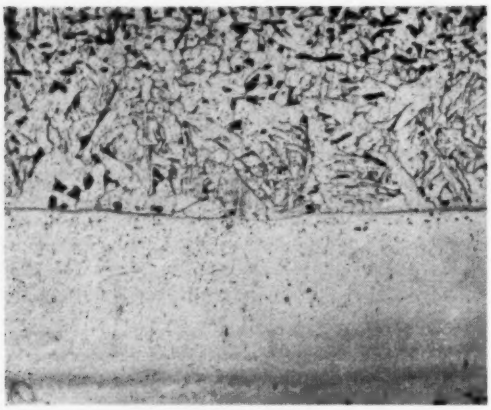


a **b**

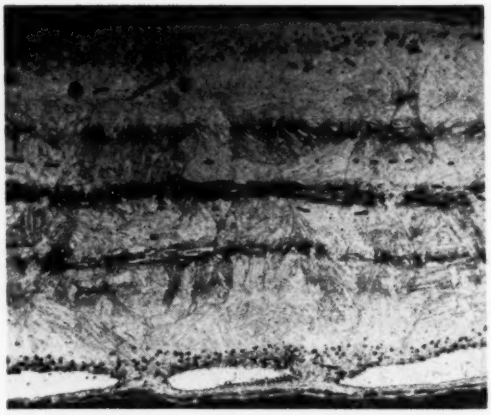
2 *Gamma-radiograph of the axe (in two projections) obtained with* Co^{60}



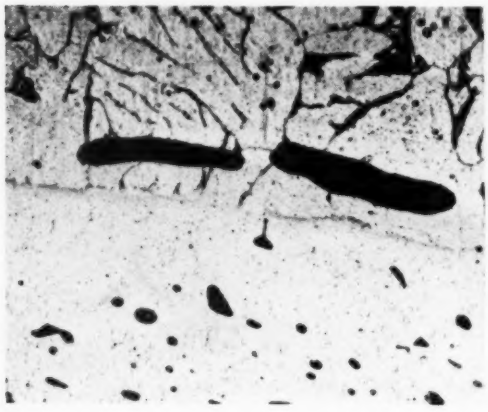
4 *Structure of layer 1: ferrite and pearlite and small slag inclusions etched in nital* ×100



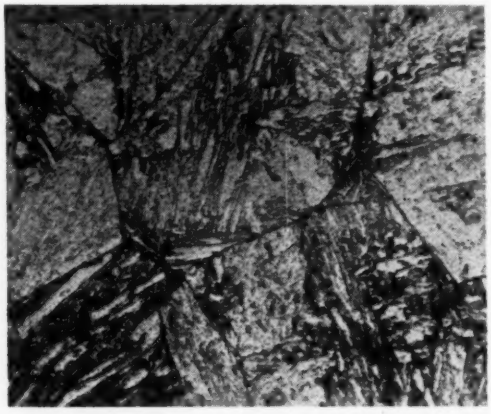
5 *Structure between layers I and II: layer I* (top) *ferrite, pearlite, and small slag inclusions; layer II* (bottom) *unaffected by etching with nital* ×100



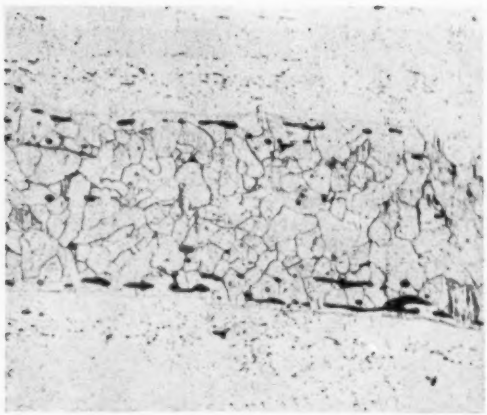
8 *Structure of layer IV near layer III* (top)*: acicular structure and a phase unaffected by etching in the form of separate conglomerations, etched in picral–*HCl ×100



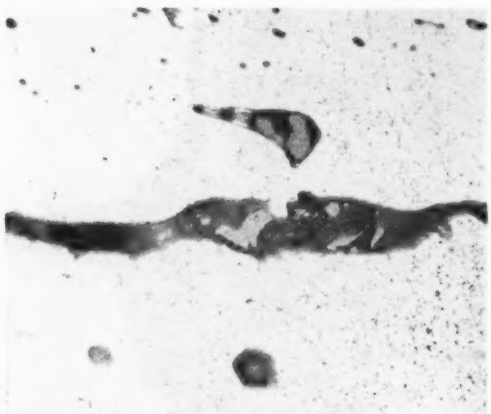
6 *As Fig.5* ×500



9 *Structure of layer II at a higher magnification: acicular structure etched in picral–*HCl ×500



7 *Structure of layers II* (top), *III* (middle), *and IV* (bottom)*: layer III, ferrite structure; layers II and IV unaffected by etching with nital* ×100



10 *Slag inclusions between layer I* (top) *and layer II* (bottom), *unetched* ×500

TABLE I Results of metallographic observation and measurements of microhardness and hardness of socketed axe from Wietrzno-Bobrka

Specimen	Source of specimen	Layer*	Components of structure	Grain size no. ASTM	Microhardness kg/mm²†	DPN, kg/mm²‡
1	Edge of axe	I	ferrite pearlite	7 traces	160	113·1
			acicular structure		354	236
		II	indefinite phase‖		179	
		III	ferrite acicular structure	6	158 323	95·8 221
		IV	indefinite phase‖		177	
		V	ferrite pearlite	7 traces	170	121·9
2	Socket of axe		pearlite ferrite	4 at grain boundaries	315 168	128·4

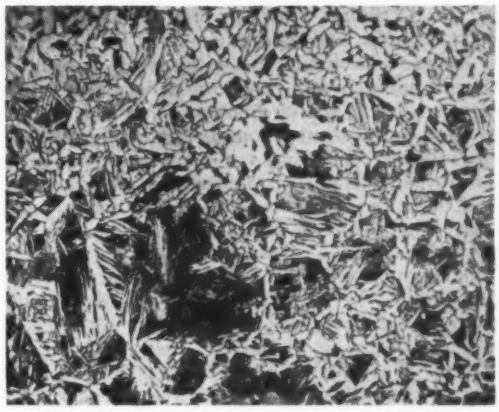
* Marking of the layers is shown in Fig.3.
† Average of 5 impressions; 50-g load applied for 15 s.
‡ Average of 2–3 impressions; 10-kg load applied for 15 s.
‖ Not etched by picral–HCl.

Figure 1 is a sketch of the axe, showing where specimens for metallographic examination were cut. The examination of several similar axes found in Poland has shown that either they had been forged from one piece of metal or the edge was forged separately and the socket put on it. By using Co^{60} it was established that the axe from Wietrzno-Bobrka was forged from one piece of metal* (Fig.2). It was not, however, a uniform metal. After etching in nital, specimen 1, cut from the axe edge, revealed that the edge consisted of five layers of different types of metal, as shown in Fig.3.

Layer I revealed a structure of soft steel, composed of ferrite and small amounts of pearlite (Fig.4). Figures 5 and 6 show the structure of the boundary between layers I and II; the latter was not affected by etching in nital. Slag inclusions are noticeable in the seam. Layer IV was also unaffected by the nital, but layer III showed a pure ferrite structure (Fig.7). In layer V which, like layer I, formed the outer part of the axe, a similar ferrite structure with an insignificant amount of pearlite was also found (*cf.* Fig.4).

* For this type of investigation it is more convenient to use Ir^{192}, which emits softer gamma radiation (*see* F. K. Naumann: *Arch. Eisenhüt.*, 1957, **28**, 575), but the author was not able to obtain this isotope of iridium.

11 *Slag inclusions in layer II, etched in nital* ×100



12 *Structure of specimen 2: pearlite and ferrite, etched in nital* ×100

The structures of layers II and IV were identified after etching in a 1:1 mixture of picral and 4%HCl; both layers were seen to have acicular structures, probably acicular ferrite (*see* Figs.8 and 9).

Moreover, in layers II and IV, along their boundaries with layers III and V, segregations of a phase were found that also remained unaffected by the picral–HCl mixture. This phase was characterized by a low microhardness (Table I). It appeared either in the form of a continuous layer or formed separate conglomerations (*see* Fig.9).

Attention should be drawn to the structure of the slag inclusions. In the layers of soft steel (I and V), the inclusions were quite small; they had a one-phase structure, black in colour (*see* Fig.6). However, inclusions of a two-phase slag often occurred in seams; on the dark background brighter crystals were apparent (Fig.10). In layers II and IV very small slag inclusions, slightly brighter in colour were found. They were clearly distributed along the central axis of these layers (Fig.11).

Specimen 2, cut from the socket of the axe, shows a structure of steel consisting of pearlite and ferrite, not quite uniformly carburized (Fig.12).

Chemical analysis of specimen I would be pointless, since it consisted of layers of various metals and the average result would be useless. Only the average contents of silicon (0·052%) and of nickel (about 4%) were determined. Since the soft steel (layers I, III, and V) probably did not contain nickel, it can be estimated that the layers of acicular structure (II and IV) contained about 8–10%Ni, which agrees with the structure observed. In specimen 2 the phosphorus content was 0·087%.

A qualitative spectrographic analysis was also carried out. The ISP–22 spectrograph was used, with an arc excited between a graphite electrode and the socket of the axe and on the surface of the edge (layer I). The spectrographs obtained were very similar: in addition to the main constituents of the iron

alloy (Fe, C, Si, and Mn), the presence of Al, As, Ba, Ca, Cu, Mg, Mo, and Ni and traces of Bi, Pb, Sn, Ti, and Zn was established. Since the graphite electrode was contaminated with vanadium, it was impossible to ascertain whether this element was present in the iron. The same elements were found when analysing specimen 1, the arc comprising various layers. The spectrogram revealed slightly different intensities of individual lines, and in particular the nickel lines appeared clearly. The results of grain-size determinations and microhardness and hardness tests are given in Table I.

The laminar structure of the edge observed seems to indicate that the small axe from Wietrzno-Bobrka was produced by deliberately welding together two different metals: an irregularly carburized soft steel and an iron containing about 8–10%Ni. It is hardly probable that the layers found were formed as the result of accidental segregation of nickel during the reduction of the metal.

The socketed axe from Wietrzno-Bobrka is the oldest known welded iron tool. The sword from Vetulonia (VII century BC) described by Panseri, Garino, and Leoni[3] was not made of welded iron and steel, as the authors supposed, but was in fact made of unevenly carburized iron, which was frequently produced in antiquity.[1]

This axe was manufactured outside Poland, in a well-developed ancient ironmaking centre, possible in the southern Balkans or in Asia Minor. Metallographic examinations of ancient iron objects from these regions may one day make it possible to identify the producers of such tools.

So far as the raw materials used to make the axe from Wietrzno-Bobrka are concerned, the soft steel was produced in bloomery furnaces. It would be interesting however, to know how a metal with such a high nickel content was obtained. Earlier writers, such as Blümner, Zimmer,[5] and others, as well as contemporary writers like Forbes,[6] Neumann,[7] and others, agree that iron with an appreciable nickel content was of meteoric origin. The chemical analyses of meteorites assembled by Zimmer indicate a high nickel content in meteorites, and investigations by Benedicks[8] show them in some cases to have an acicular structure.

However, the present author believes that iron with a high nickel content could be obtained from ore containing both metals. It is unlikely that in the VIII–IV century BC, when the knowledge of iron production was already well developed, men were still using meteoric metal. Ancient writers, such as Aristotle,[9] Daimachos, Pliny, and others, mention various kinds of iron. This classification was undoubtedly based on the degree and evenness of carburization and the phosphorus content. The nickel content might be another means of classification.

However the high-nickel iron was obtained, it may be stated that the craftsman who produced this tool had not only succeeded in welding various iron alloys but also knew how to distinguish between different iron alloys, namely the soft steel and the high-nickel iron. This indicates that a very high degree of knowledge of iron alloys and their treatment had been achieved by ancient ironworkers as early as the VIII–IV centuries BC.

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News of Special Reports

Two new volumes have recently been published in the Institute's Special Report Series, and may be obtained on application to the Secretary.

Precipitation Processes in Steel is the title of no.64, which is a full report of a meeting held in Sheffield in July 1958, and organized by the Department of Metallurgy of Sheffield University. Sixteen papers by leading workers in this field, from Belgium, France, Germany, Sweden, the UK, and the USA were presented. They were divided into four groups, covering precipitation in ferritic steels, precipitation in austenitic steels, intergranular fracture in steels, and precipitation during creep. These papers are printed in full in the report, together with the lively and informative discussions at the meeting. There is little doubt that this is the most valuable book published in recent years on precipitation processes in alloy steels, a vitally important subject today, when alloy steels are required for a great range of new applications.

Special Report no.65 is entitled *Handling and Treatment of Iron Ores*, and is a report of the meeting of the Institute's Iron and Steel Engineers Group held in Amsterdam in April 1959. Following an authoritative survey of the world iron-ore situation by Mr C. R. Wheeler, C.B.E., there are a number of papers dealing with various aspects of the subject. The installations at the Port of Rotterdam and IJmuiden in Holland, at Contrecoeur and Seven Islands, Canada, and at Margam and Cardiff in South Wales are described in a series of papers. There is an excellent survey of unloading facilities in the USA and Canada by Dr H. R. Mills of BISRA, and Mr T. V. Nicholson of the BTC contributes an account of the rail transportation of iron ores in the UK. In addition, there are papers on crushing, screening, handling, and blending plant for iron ores.

Report no.64 costs £4 4*s* 0*d* (£3 3*s* 0*d* to members of the Institute) and report no.65 costs £3 5*s* 0*d* both to members and non-members. Postage is 1*s*.

Diffusion and solubility of sulphur in iron and silicon–iron alloys

Norman G. Ainslie and Alan U. Seybolt

SYNOPSIS

The behaviour of sulphur in the iron-rich portion of the iron–silicon–manganese–sulphur system was studied. The volume diffusion coefficient of sulphur in pure iron and 3·25% silicon–iron was measured as a function of temperature. Also, the solubility of sulphur in pure iron, and 3·25% silicon–iron, was measured as a function of temperature as well as the solubility product of manganese and sulphur in 3·25% silicon–iron. 1710

INTRODUCTION

THE HARMFUL EFFECTS that sulphur has upon the properties of iron alloys are well known, hot shortness being the most familiar. It is not well known, however, that in a very important class of alloys sulphur can have a beneficial effect. In the commercial processing of soft-magnetic silicon–iron sheet sulphur is apparently essential to the development of the desirable (110) [001], or 'cube-on-edge', secondary recrystallization texture.[1,2] Because of the commercial importance of this material, a thermodynamic investigation of the iron-rich portions of the silicon–manganese–sulphur–iron system was undertaken in the hope of achieving a better understanding of existing technology.

GENERAL CONSIDERATIONS, EXPERIMENTAL

Chemistry

The known reactions of metallurgical importance involving sulphur were summarized by Richardson and Jeffes[3] in 1952. In their literature review they rationalized the reported values for the thermodynamic functions and recommended what were thought to be the best values. Referring to the work of Pruener,[4] Pruener and Schupp,[5] and Randall and von Bichowsky,[6] they recommend the following:

$$2\,H_2S \rightarrow S_2 + 2\,H_2 \qquad \text{.....(1)}$$
$$\Delta G^\circ = 43\,160 - 23{\cdot}61T \ (25^\circ\text{–}1927^\circ\text{C})$$

Also, referring to the measurements of Alcock and Richardson,[7] they recommend:

$$2\,Fe + S_2 = 2\,FeS \qquad \text{.....(2)}$$
$$\Delta G^\circ = -71\,820 + 25{\cdot}12T (139^\circ - 907^\circ\text{C})$$
$$\Delta G^\circ = -72\,140 + 25{\cdot}48T (907^\circ - 988^\circ\text{C})$$

Combining equations (1) and (2), and assuming that both Fe and FeS are pure, we obtain:

$$FeS + H_2 = H_2S + Fe \qquad \text{.....(3)}$$
$$\log\left(\frac{H_2S}{H_2}\right) = \frac{-3132}{T} + 0{\cdot}165 \ (139^\circ - 907^\circ\text{C})$$
$$\log\left(\frac{H_2S}{H_2}\right) = \frac{-3167}{T} + 0{\cdot}204 \ (907^\circ - 988^\circ\text{C})$$

Manuscript received 23 March 1959.
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Rosenqvist[8] more recently determined the ratio of H_2S/H_2 for the same reaction:

$$\log\left(\frac{H_2S}{H_2}\right) = \frac{-3100}{T} + 0{\cdot}179 \ (500^\circ - 988^\circ\text{C})$$

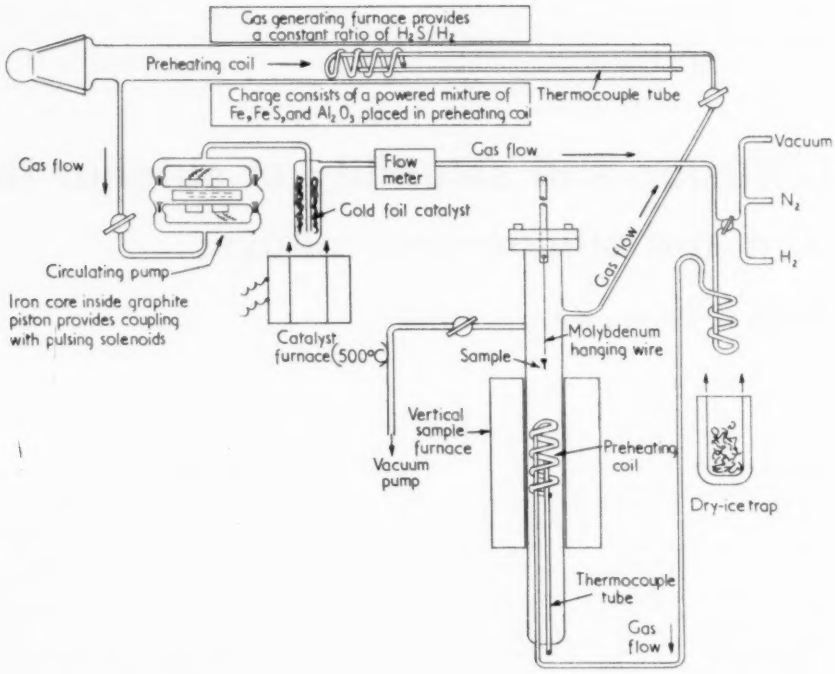
The agreement is good.

It was by using reaction (3) that most of the experiments reported in this paper were carried out. The specimens were sulphurized in furnace atmospheres containing H_2S and H_2 in various ratios, the exact ratio desired being obtained by merely adjusting the temperature of reaction (3). In general the temperature of the sample to be sulphurized differed from that at which reaction (3) was to be carried out; moderately elaborate equipment was therefore required.

Apparatus

The apparatus, which is similar to that used by Turkdogan, Ignatowicz, and Pearson,[9] is shown schematically in Fig.1. In one furnace, the gas-generating furnace, hydrogen is passed over a charge consisting of a mixture of pure iron powder, FeS powder, and Al_2O_3 granules. The inert Al_2O_3 served to separate the particles of iron and FeS and thereby allow the hydrogen to circulate easily through the charge. It was effective to the extent that overall sintering of the charge was prevented.

The equilibrium gas mixture was circulated through glass tubing to another furnace in which the specimen to be sulphurized was suspended. After flowing over the specimen, the gas mixture was returned by means of a circulating pump (shown in Fig.1) to the gas-generating furnace and replenished. In this way a specimen could be exposed to any desired sulphur potential as determined by the ratio H_2S/H_2. Gold foil kept at 500°C was used in an attempt to catalyze any oxygen present to water. Whether it was effective or



1 *Schematic diagram of apparatus*

not is not known. However, ice was usually found in the −78°C dry ice trap after each run.

Both furnace tubes were made of a high-temperature mullite-type porcelain. The gas mixture was preheated by passing it through a helix of $\frac{1}{8}$-in. dia. quartz tubing having 8–10 turns which was placed in the centre of the furnace hot zone so that the gas mixture was at temperature before it contacted the specimen. In this manner thermal diffusion errors were reduced if not eliminated completely. In addition to the use of preheating coils, thermal diffusion was reduced by using the rather high flow rate of 300 ml/min. The recommendation of Darken and Gurry[10] to cause the gas to flow upward, rather than downward, through a vertical furnace was followed in the case of the specimen furnace to minimize thermal diffusion.

Temperatures were measured with Pt/Pt–10%Rh thermocouples placed in dead-end quartz tubes that projected into the furnace hot zones. Furnace temperatures were maintained to ±3°C.

Analysis

The FeS in the gas-generating furnace contained fairly high levels of S^{35}, a beta-particle emitter of maximum energy, 0·167 MeV, and half-life 87·1 days. Roughly 30 mc of radiation were incorporated into each 1·5 g of sulphur.

Specimens which ultimately became sulphurized with the radio-sulphur were related to one another through their respective levels of radioactivity. Radioactivity determinations were made using a thin end-window Geiger tube. Care was taken to ensure identical counting geometry for each specimen.

Experiments showed that the counting rate of any given specimen was fairly sensitive to the condition of its surface. One could get only poor reproducibility on successive counts from a heavily etched surface. Therefore, all radioactivity measurements, with the exception of those on the diffusion specimens, were made on surfaces that had been metallographically polished through the papers to the 3 μ diamond cloth. In this condition reproducibility was excellent even after the surface had been metallographically etched.

All radioactivity determinations were corrected for errors resulting from coincident radioactive disintegrations using the expression:

$$N=\frac{N_0}{1-\sigma N_0}$$

where N is the true incident radiation in counts/s, N_0 the measured radiation, and σ the 'dead time'[11] of the Geiger tube at the particular operating voltage.

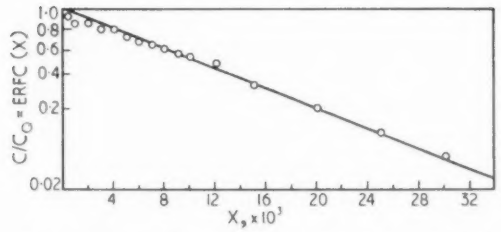
In addition to permitting quick evaluation of the sulphur levels, the tracer technique also permitted further study with auto-radiography which proved useful in the diffusion work.

Precautions were taken to correct for radioactive decay. Careful chemical analyses relating percentage sulphur to radioactivity were carried out at Pittsfield, Massachusetts, in the Transformer Laboratory of the General Electric Co.; the technique, developed by Fulton and Fryxell,[12] was reproducible at the 95% confidence level to within ±0·0005%S.

DIFFUSION OF SULPHUR IN 3·25% SILICON–IRON AND IN PURE ALPHA IRON

3·25% silicon–iron

The diffusion coefficient of sulphur in 3·25% silicon–iron, which is ferritic, was determined in the temperature range of 900–1 300°C by analyzing radioactivity *v.* penetration curves. The data were treated as though



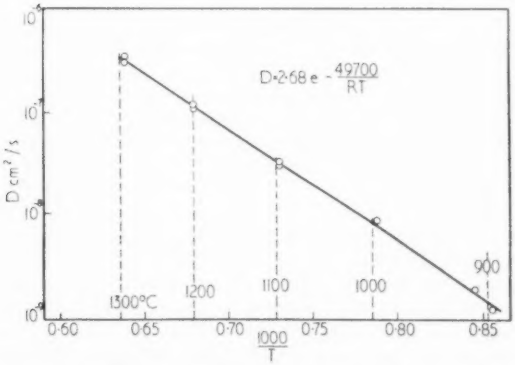
2 *Sample concentration–penetration curve for silicon–iron specimen that underwent a diffusion anneal at 988°C*

the system were a binary comprised of sulphur as one component and silicon–iron as the other. It was assumed that diffusion occurs mainly by volume diffusion and that the diffusion coefficient, D, for sulphur in this particular alloy is constant for a given temperature. Although it was clearly established in this work that the grain boundary diffusion rate[13, 14] is quite noticeably greater than the volume diffusion rate at temperatures up to 1000°C, the assumption of volume diffusion is considered justified since large-grained samples ($\frac{1}{4}$-in. dia.) were used which precluded any appreciable increase in the diffusion flux due to conduction along grain boundaries. The fact that the hypothesized curves of concentration of sulphur *v.* penetration were obeyed quite closely is evidence that the assumptions are not grossly in error. More convincing evidence is the fact that the log D *v.* $1/T$ plot is linear.

Silicon–iron discs, $\frac{1}{8}$-in. thick × 1 in. dia. were prepared from a 6-lb vacuum-induction laboratory melt of electrolytic iron and pure ferrosilicon. The discs were annealed for several hours at 1300°C in dry hydrogen in order to achieve uniformity and a large grain size.

Diffusion anneals were accomplished by hanging the discs for various times in the specimen furnace of Fig.1 through which was circulating a constant mixture of H_2S and H_2. Sulphur entered predominantly through the disc faces.

Concentration–penetration curves were determined for one or both faces of each disc by making successive lathe cuts and counting radioactivity after each cut;



3 *Volume diffusion coefficient, D, v. 1000/T for sulphur in 3·25% silicon–iron*

TABLE 1 Diffusion coefficient of sulphur in 3·25% silicon–iron alloys as calculated using the empirical expression

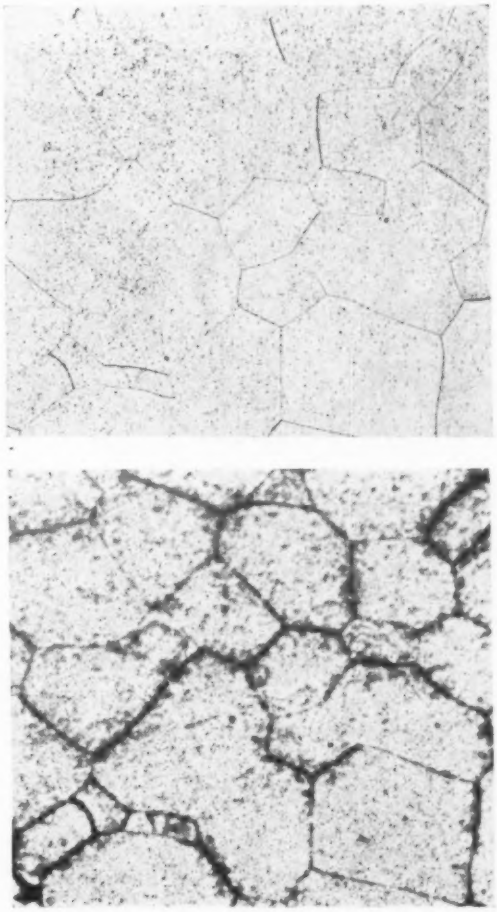
Temperature, °C	D, cm^2/s
900	$1{\cdot}47 \times 10^{-9}$
950	$3{\cdot}51 \times 10^{-9}$
1000	$8{\cdot}83 \times 10^{-9}$
1050	$1{\cdot}65 \times 10^{-8}$
1100	$3{\cdot}28 \times 10^{-8}$
1150	$6{\cdot}22 \times 10^{-8}$
1175	$8{\cdot}43 \times 10^{-8}$
1200	$1{\cdot}13 \times 10^{-7}$
1250	$1{\cdot}97 \times 10^{-7}$
1300	$3{\cdot}32 \times 10^{-7}$

the data were fitted to an error function[15] solution to the diffusion equation given by:

$$\frac{C}{C_0} = \operatorname{erfc} x = 1 - \frac{2}{\sqrt{\pi}} \int_0^{\frac{x}{2\sqrt{Dt}}} e^{-y^2} dy$$

where

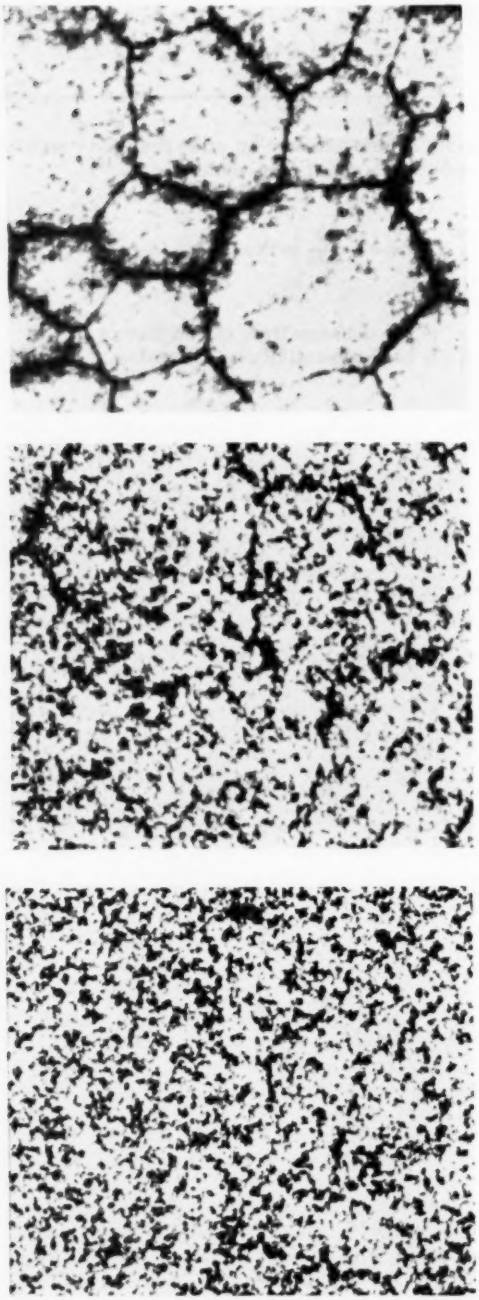
x is the distance from the surface of the disc
C is the radioactivity at a distance x



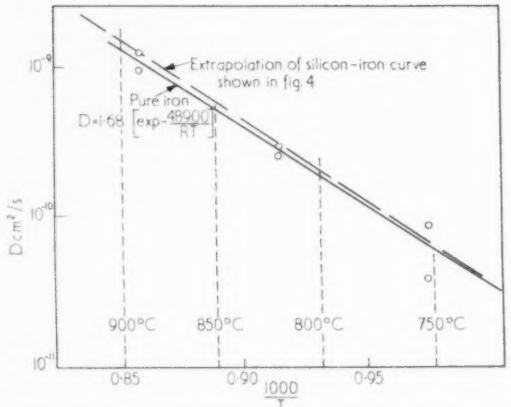
4 *Comparison between photomicrograph and auto-radiograph of silicon–iron specimen that underwent diffusion anneal at 950°C*

C_0 is the radioactivity at $x=0$
t is the time of the diffusion anneal
D is the volume diffusion coefficient
y is an integration variable.

Figure 2 shows the concentration–penetration curve for the diffusion run carried out at 988°C. The figure shows C/C_0 plotted *v.* x on probability coordinates; it is apparent that the error function hypothesis is satisfied by the data. Figure 3 shows the plot of D *v.* $1/T$.



5 *Silicon–iron specimens given diffusion anneals at indicated temperatures. Note that fast grain-boundary diffusion is evident still at 1 000 C*



6 *Comparison between measured volume diffusion coefficients of pure iron single-crystals and the extrapolated values for silicon–iron*

The variation of the diffusion coefficient with temperature for sulphur in 3·25% silicon–iron was found to be:

$$D = 2{\cdot}68 \exp\left[-49\,700/\boldsymbol{RT}\right] (900\text{–}1\,300^{\circ}\text{C}) \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The activation energy of 49 700 cal/mole is a reasonable value for volume diffusion of a substitutional element. Table I gives the diffusion coefficients at selected temperatures.

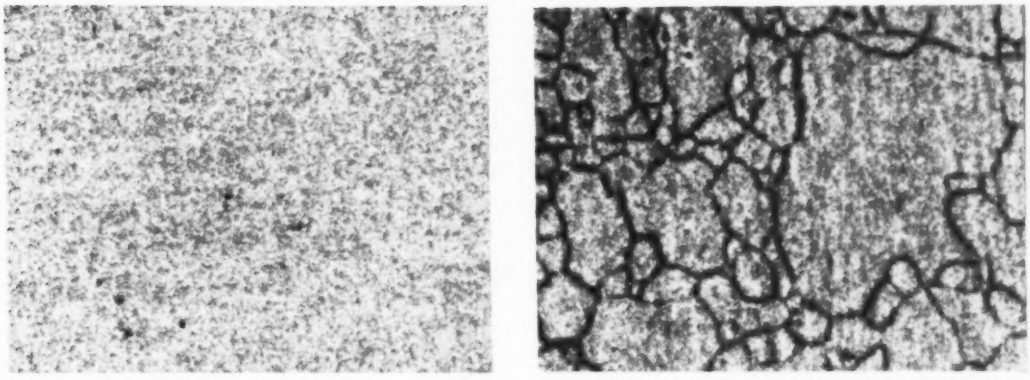
Auto-radiographs were also prepared from the silicon–iron diffusion specimens by placing them in firm contact with X-ray film for periods up to four days. Figure 4 shows a comparison between one of the auto-radiographs and a photomicrograph of the same area. Fast grain-boundary diffusion obviously occurred in this sample. Notice how the intensity of darkening varies from grain boundary to grain boundary.

One expects the volume diffusion rate to increase more rapidly with temperature than the grain-boundary diffusion rate, and, therefore, the difference between them to become less as the temperature goes up. Figure 5 shows that this is so. In fact, grain-boundary diffusion is no longer in evidence at temperatures above 1000°C.

Pure alpha iron

In addition to the diffusion measurements on silicon–iron, measurements were also attempted in pure α-iron, first with polycrystals, and later with single crystals when the writers were able to prepare them in thick sections. The technique for making single crystals of pure iron, described elsewhere,[16] derived in certain important aspects from the earlier work of Talbot,[17] and Flanagan.[18]

The concentration–penetration curves of the polycrystalline iron in general fitted the error function hypothesis quite poorly, probably because of effects arising from a large flux contribution from the grain boundaries. Better results were obtained with the single crystals although even they were not as consistent as the high temperature silicon–iron data. Figure 6 shows a plot of log D *v.* $1/T$ for sulphur in single crystals of pure α-iron. It agrees fairly well with



7 *Comparison between the auto-radiographs of a single crystal and a polycrystal of pure iron. These specimens, 0·006 in. thick, were equilibrated simultaneously at 890°C for two weeks. The atmosphere used was a mixture of* H_2S *and* H_2 *whose ratio,* H_2S/H_2, *was roughly 1/2 that needed for bulk* FeS *formation*

the extrapolation of the curve for silicon–iron which is also shown. The curve for the pure iron data was drawn to fit the high temperature points and not the two points at the lowest temperature because of the uncertainty in choosing the proper D value for this low temperature; the level of radioactivity in these two low temperature specimens was not high enough for reliable D values. However, since the points do straddle the curve, they are included. The measured variation of D with temperature for sulphur in pure single crystals of α-iron is given by:

$$D = 1{\cdot}68 \exp[-48900/\boldsymbol{R}T] (700\text{–}900^\circ\text{C})$$

based upon the points at the two highest temperatures shown in Fig.6. Although Hart[19] has shown for the case of self-diffusion that the log D *v.* $1/T$ plot may be expected to deviate from a straight line at low temperatures due to effects arising from random arrays of dislocations, the deviations would be quite small in general, and very likely less than the range of scatter evident in Fig.6.

The polycrystalline iron diffusion specimens all had concentration profiles that indicated a large contribution to the diffusion flux by rapid diffusion along grain boundaries; that is, they deviated markedly from straight lines on error function plots such as shown in Fig.2. The deviation was in a direction qualitatively explainable by grain-boundary diffusion: however, the degree of deviation was variable, being quite sensitive to the state of strain at the instant the specimen was lowered into the furnace hot zone. Specimens that entered the diffusion anneal in the highly work-hardened state apparently recrystallized immediately. These recrystallized grains, however, were not permitted to grow very rapidly because the sulphur, rushing in along the grain boundaries, locked them in place. The result was a very large grain-boundary effect because of the small grain size, and hence a large deviation from linearity on the error function plot. In addition, the data fitted Fisher's[13] grain-boundary model as poorly as it did the error function. It was therefore not possible to estimate the grain-boundary diffusion coefficient.

By contrast, specimens that were recrystallized and grain-coarsened by a vacuum anneal before entering the diffusion anneal exhibited relatively small, though significant, deviations from linearity when their concentration–penetration curves were plotted on probability graph paper. Therefore, nothing definite can be said concerning grain-boundary diffusion coefficient of sulphur in pure α-iron, save that it must be many orders of magnitude greater than the lattice diffusion coefficient. The auto-radiographs of the pure iron polycrystals are similar to those for silicon–iron, shown in Figs.4 and 5, and will not be reproduced here.

To the writers' knowledge the only other diffusion work done on sulphur in iron alloys was by Bramley, Haywood, Cooper, and Watts[20] for rather impure γ-iron; they report D for five temperatures. It was found that the following expression fits their data best:

$$D = 2{\cdot}37 \times 10^{-6} \exp[-21\,300/\boldsymbol{R}T]$$

(γ-iron, Bramley, *et al.*[20])

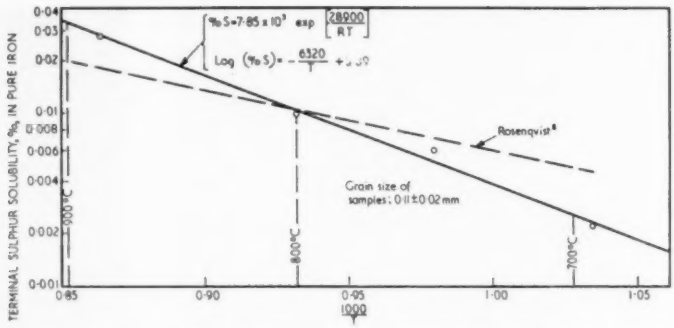
Seith,[21] in his compilation of diffusion data, calculates an activation energy of 26700 cal/mole for this work.

At the α–γ transformation temperature, 910°C, the diffusion coefficient of Bramley *et al.*, γ-iron is less by a factor of seven than that for the α-iron reported in this work. That sulphur is a slower diffuser in γ- than in α-iron at the transformation temperature is not surprising since other materials behave similarly in this respect (*see* Seith[21]). The surprising feature here is that the activation energy for sulphur diffusion in γ-iron appears less by a factor of 2·5 than that for the α-iron. The reverse is usually true. Their value for the activation energy is in fact more like that of an interstitial solute than a substitutional.

EQUILIBRIUM SOLUBILITY OF SULPHUR

Pure iron

The solubility of sulphur in α-iron was measured using the apparatus shown in Fig.1. Sheet specimens of pure (ferrovac) iron, 0·003 in. thick, were suspended in the sample furnace of Fig.1. The gas-generating furnace was operated at a temperature equal to that of the specimen furnace so that a ratio of H_2S/H_2 just able to saturate the specimens with sulphur was achieved. Specimens were held at temperatures for times that permitted complete diffusion (three weeks in the case of the sample equilibrated at 695°C). The interest here was, not so much knowledge of the solubilities *per se*, but rather to test the experimental technique of



8 *Solubility of sulphur in polycrystalline pure iron as a function of temperature*

repeating Rosenqvist's work.[8, 22] Although the details of Rosenqvist's work on α-iron are incomplete, he reports solubility results. During preliminary attempts to measure this equilibrium solubility of sulphur in pure iron α-iron, it was found quite difficult to achieve even fair reproducibility. Rosenqvist, it will be noted, had the same trouble. The puzzling behaviour was finally understood when sulphur was seen on autoradiographs to segregate in astonishing quantities at grain boundaries (*see* Fig.7), and that variations in grain size were the cause of the scatter. Studies concerning the nature of this grain boundary segregation will be reported later. The evidence to date indicates that sulphur segregates as a solute and not as a precipitate.

Figure 8 shows the sulphur solubility *v.* $1/T$ as determined in this work as well as that found by Rosenqvist. The specimens used in the present work had grain 'diameters' (mean linear intercept lengths, L/N) of $0{\cdot}11 \pm 0{\cdot}02$ mm. The expression for sulphur solubility in α-iron as determined in this experiment is given by:

$$\%S_{max} = 7{\cdot}85 \times 10^3 \exp\left[28900/\boldsymbol{RT}\right]$$

or

$$\log\left(\%S_{max}\right) = -\frac{6320}{T} + 3{\cdot}89$$

Grain size: $L/N = 0{\cdot}11 \pm 0{\cdot}02$ mm; Temp. range: 650–910°C

Table II gives the calculated solubilities at selected temperatures.

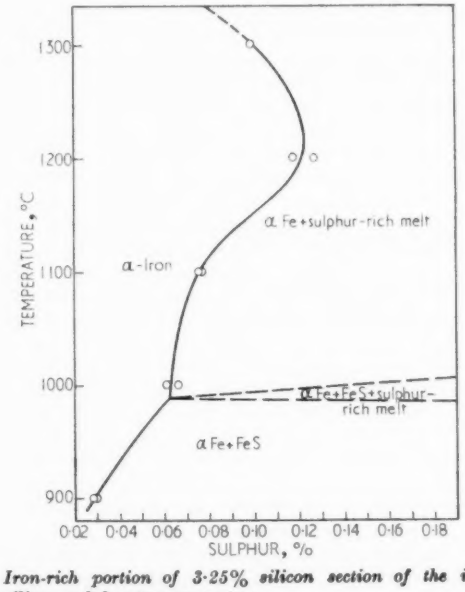
Pure silicon–iron

A vacuum melted heat of 3·25% silicon–iron (3·2%Si by analysis) was prepared from electrolytic iron and pure silicon metal. After rolling to 0·012 in. it was annealed for several hours at 1300°C in pure dry hydrogen in order to eliminate sulphur and carbon, and to achieve a large grain size. One is able to realize a large grain size in silicon–iron this way since, if the carbon content is sufficiently low[23] the alloy is ferritic up to the melting point. The grain size was measured to be ~ $\frac{3}{16}$ in. dia. at this stage.

Because the ratio of H_2S/H_2 required to saturate these silicon–iron specimens with sulphur was not known, and because, if this gas ratio were exceeded, the specimens would be rapidly converted to a sulphur-rich phase, a slightly different technique was used to saturate the samples: the lowest sulphide of cobalt, CO_4S_3, was prepared from sulphur and a stoichiometric excess of pure cobalt powder. The silicon–iron specimens were sealed off in quartz capsules containing hydrogen and an amount of cobalt sulphide calculated to contain several times enough sulphur to saturate the specimens at the equilibrating temperature. The necessary amount of CO_4S_3 was estimated by extrapolating the curve of Fig.8 to high temperatures and reading off the sulphur percentage necessary to saturate pure iron. Since CO_4S_3 is less stable than FeS,[3] the sulphur was transferred by the H_2S to the silicon–iron specimen. When equilibrium was attained at the chosen temperature (diffusion times were calculated), the silicon–iron specimens were saturated with sulphur and contained an equilibrium, sulphur-rich, phase on the surface. It remained only to remove this surface phase by abrasion and to analyse that which remained for sulphur. In the binary iron–sulphur system, saturated γ-iron forms a two-phase mixture with a sulphur-rich melt above 988°C (*see* refs.8

TABLE II Solubility of sulphur in pure alpha iron as calculated using the empirical expression

Temperature, °C	Sulphur, wt-%
650	0·0012
700	0·0025
750	0·0052
800	0·0098
850	0·0182
900	0·0324



9 *Iron-rich portion of 3·25% silicon section of the iron–silicon–sulphur ternary system*

TABLE III Solubility of sulphur in pure 3·25% silicon–iron alloys

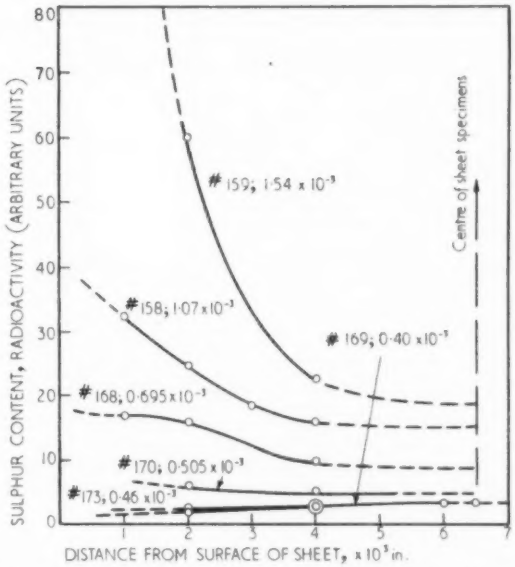
Temperature, °C	Sulphur, wt·%
900	0·029
1000	0·063
1100	0·076
1200	0·122
1300	0·098

and 22). One might therefore expect in the 3·25%Si section of the iron–silicon–sulphur ternary to find a similar sulphur-rich melt above a temperature near 988°C and a corresponding kink in the solubility curve at this temperature. The data permitted such a discontinuity but did not require it; Fig.9 shows results. Table III gives the solubility at selected temperatures.

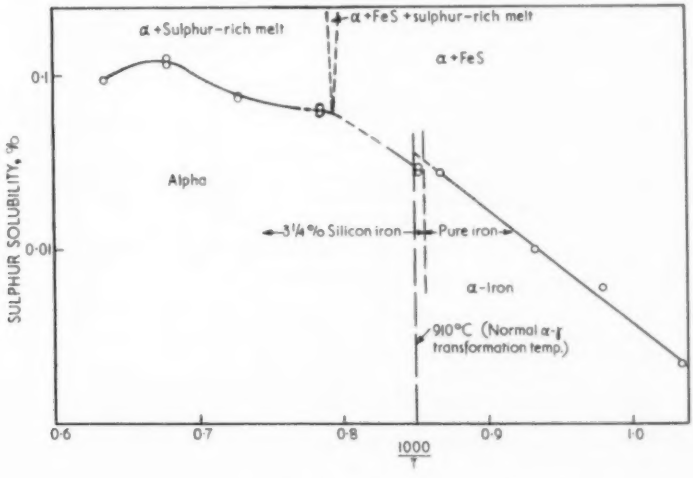
The specimens that were equilibrated at 900° and 1000°C showed grain-boundary segregation of sulphur on auto-radiographs. It was barely visible at 1000°C and completely absent at all higher temperatures. Since the auto-radiographs do not differ from the others shown in this report, they will not be shown. The grain size was sufficiently large to preclude a sensible increase in sulphur solubility due to grain-boundary segregation. If one extrapolates the solubility curve for sulphur in pure iron to 900°C and compares the %S with that for the silicon–iron at the same temperature, one finds that the relatively fine-grained pure iron holds more sulphur than the silicon–iron (*see* Fig.10).

Solubility product of sulphur and manganese in 3·25% silicon–iron

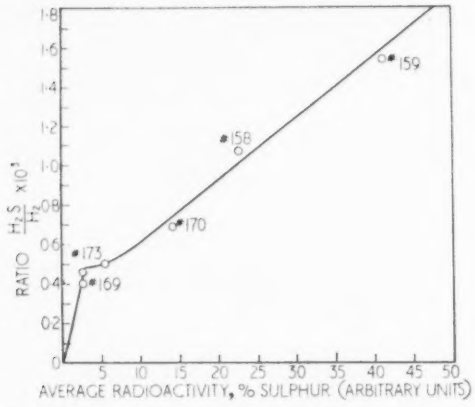
When manganese and sulphur, in dilute solid solution, are in equilibrium with manganese sulphide, we may write for the reaction, $MnS \rightarrow Mn + S$, $K_{sp} = [\%Mn][\%S]$ if the activity of MnS is constant. The solubility product, K_{sp}, was measured as follows: silicon–iron specimens containing manganese were suspended in the sample furnace shown in Fig.1, and held sufficiently long for complete diffusion of sulphur to occur. The ratio of H_2S/H_2 of the furnace atmosphere was controlled at a different value for each specimen by simply controlling the temperature of the gas-generating furnace; the ratio of H_2S/H_2 uniquely determined the sulphur potential of the specimens at equilibrium. The result was a series of specimens that was equilibrated at a given temperature, each sample in the series having been exposed to a different H_2S/H_2 ratio, and hence containing a different percentage of S. The problem was then to establish criteria for deciding at just which H_2S/H_2 ratio manganese sulphide formed in the alloy. Knowing this ratio, one needed only to analyse for sulphur in the particular specimen that experienced the critical ratio of H_2S/H_2 (or rather just under the critical ratio) to have sufficient data to compute the solubility product. The criteria used will be described in detail later.


SULPHUR CONTENT, RADIOACTIVITY (ARBITRARY UNITS)
DISTANCE FROM SURFACE OF SHEET, x 10⁻³ in.
Centre of sheet specimens
#159; 1·54 x 10⁻³
#158; 1·07 x 10⁻³
#169; 0·40 x 10⁻³
#168; 0·695 x 10⁻³
#170; 0·505 x 10⁻³
#173; 0·46 x 10⁻³

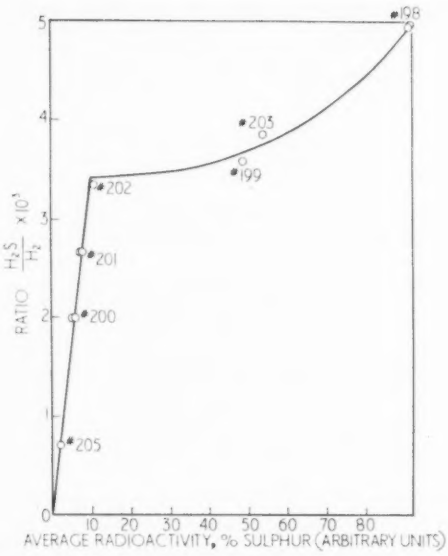
11 *Plot of radioactivity (∝ percentage sulphur) v. distance from the surfaces of the silicon–iron sheet specimens upon which* MnS *solubility product studies at 1027 ± 3°C were made. The numbers next to the specimen numbers give the ratio of* H_2S/H_2 *of the furnace atmosphere. Note how all specimens except Nos.169 and 173 curve upward to the surface, indicating an* MnS *subscale formation. One would decide on the basis of these curves that the critical ratio of* H_2S/H_2 *lies between* $0{\cdot}46 \times 10^{-3}$ *and* $0{\cdot}505 \times 10^{-3}$, *(see also Fig.12)*



10 *Comparison of the sulphur solubility in pure iron to that in 3·25% silicon–iron as a function of temperature*



12 *Data of Fig.11 replotted: ratio of* H_2S/H_2 *v. average radioactivity across the individual sheet specimens. One would decide on the basis of this curve that the critical ratio of* H_2S/H_2 *lies between* $0{\cdot}46 \times 10^{-3}$ *and* $0{\cdot}505 \times 10^{-3}$*, in agreement with the conclusion reached using Fig.11*



14 *Ratio of* H_2S/H_2 *v. average radioactivity of specimens upon which* MnS *solubility product studies at* $1234 \pm 5°C$ *were made. One would decide on the basis of this curve that the critical ratio of* H_2S/H_2 *lies between* $3{\cdot}34 \times 10^{-3}$ *and* $3{\cdot}57 \times 10^{-3}$

The specimens used were 0·012-in. sheet. After processing, but before equilibration, they had the following analysis:

Si	Mn	C	S	Fe
3·3%	0·139%	0·001%	0·0004 ± 0·0003%	Balance

The distribution of manganese across the thickness of the sheet was determined using X-ray emission analysis to be uniform within the limits of the technique, namely, ±3% of the average manganese content.

The material was obtained by preparing a 6-lb vacuum melt and casting it into a graphite mould. After machining the surfaces, the ingot was hot-rolled direct to 0·080 in. and then cold rolled direct to 0·012 in. The 0·012-in. sheet was then annealed for 8 h at 1300°C in pure dry hydrogen so as to remove sulphur and carbon and to achieve a large grain size. The samples had an average grain size of $\approx \frac{1}{4}$ in.

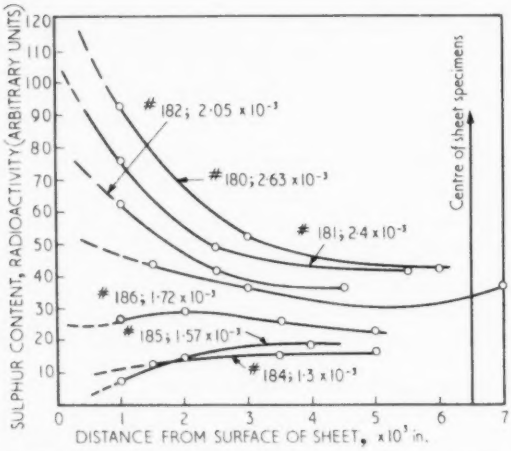
The solubility product of manganese and sulphur in this material was determined at three temperatures: 1027°, 1154°, and 1234°C. The critical ratio of H_2S/H_2, that is the ratio that would just form manganese sulphide at each temperature, was determined on the basis of two criteria:

Composition profile

The percentage sulphur profile across the thickness of the sheet specimens would, if complete diffusion occurred, be expected to be horizontal if manganese sulphide did not form. If MnS did form, it would form first in the surface layers, thereby impoverishing the surface layers of manganese and result in the diffusion of manganese to the surface layers from the centre of the sheet. The result at equilibrium would be a higher sulphur content in the surface layers than in the centre of the sheet.

H_2S/H_2 ratio v. percent sulphur plot

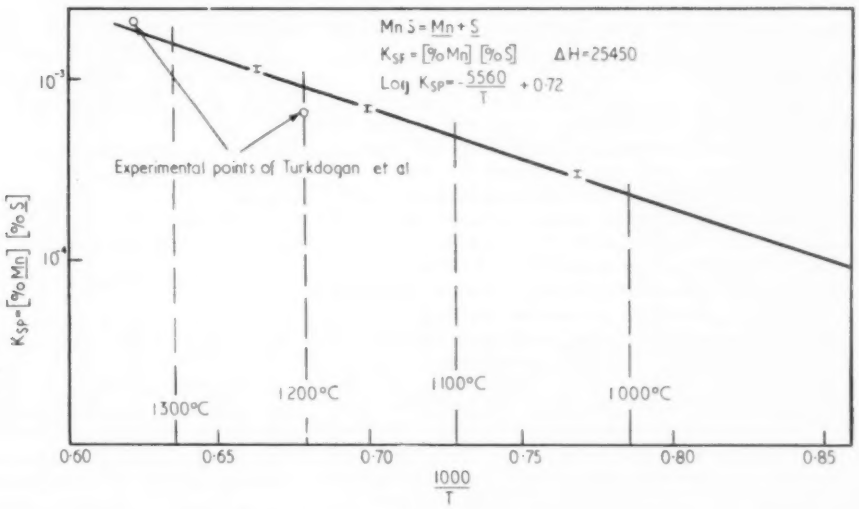
As the H_2S/H_2 ratio increases, the percentage of sulphur in solid solution increases linearly (if Henry's law is obeyed) until it reaches a level that is sufficient to form manganese sulphide. A break in the curve appears at this point as the total sulphur content is



13 *Plot of radioactivity (∝ percentage sulphur) v. distance from the surfaces of the silicon–iron sheet specimens upon which* MnS *solubility product studies at* $1154 \pm 3°C$ *were made. Note how all specimens except nos.184 and 185 curve upward to the surface, indicating an* MnS *subscale formation. One would decide on the basis of these curves that the critical ratio of* H_2S/H_2 *lies between* $1{\cdot}57 \times 10^{-3}$ *and* $1{\cdot}72 \times 10^{-3}$

TABLE IV Solubility product of MnS in 3·25% silicon–iron alloys as calculated using the empirical expression

Temperature, °C	K_{sp}
1000	0·000224
1050	0·000331
1100	0·000468
1150	0·000645
1200	0·000890
1250	0·001175



15 *Solubility product of manganese and sulphur in 3·25% silicon–iron as a function of temperature*

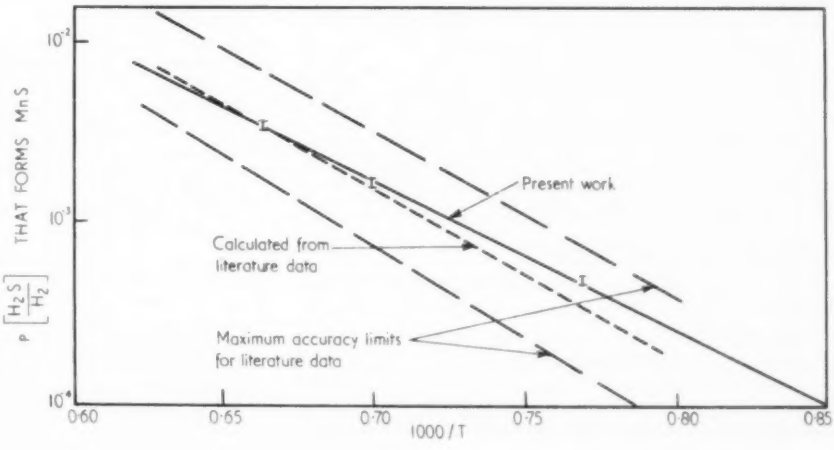
now represented not only by the solid solution level of sulphur, but, in addition, an amount of sulphur tied up in the form of MnS precipitate.

To use the first criterion each sample had to be mounted flat and have its radioactivity measured on several polished sections below and parallel to the surface. For the two lowest equilibrating temperatures this criterion proved to be the more sensitive test because of the difficulty of attaining equilibrium H_2S/H_2 ratios lying sufficiently below the critical ratio.

Figure 11 shows the profiles of concentration *v.* distance from the surfaces of the specimens that were equilibrated at 1027°C. The concentration was measured in terms of radioactivity. It will be noted that those samples which experienced the highest ratios of H_2S/H_2 exhibited a marked fall-off in radioactivity in going from the surface to the centre of the sheet. The degree of this fall-off becomes less as the H_2S/H_2 ratio is lowered until the curve becomes virtually flat for H_2S/H_2 ratios below a certain value. If the low H_2S/H_2 ratio curves in Fig.11 are carefully examined it will be seen that in fact the reverse type of profile appears: the radioactivity *increases* slightly as one measures nearer the centre of the sheet. The authors are unable to explain this behaviour; they simply chose as the critical ratio of H_2S/H_2, one lying between that which causes a rise in radioactivity toward the centre of the sheet and that which causes a fall. The critical ratio thus lies between $0{\cdot}40\times10^{-3}$ and $0{\cdot}46\times10^{-3}$.

One comes to the same conclusion using the second criterion. Figure 12 shows the average of the radioactivity readings taken at the different depths plotted against the H_2S/H_2 ratios. The data permit only one conclusion, namely, the critical H_2S/H_2 ratio lies between the two values given above.

At the next higher temperature, 1154°C, a similar decision was made on the basis of the first criterion. Figure 13 shows the concentration profiles. At this temperature, however, the decision went unsupported by the second criterion which permitted no conclusion for the following reason: the radioactivity profiles of the two samples equilibrated below the critical H_2S/H_2 ratio increases more markedly toward the centre of the sheet than did their opposite numbers at 1027°C. As a result the average radioactivity across the sheet was much less meaningful. It must be emphasized that the reason for the higher radioactivity at the centre of the sheet is not known. The manganese distribution across the thickness of these specimens



16 *Critical ratio of H_2S/H_2 necessary to form MnS in the 3·25% silicon–iron alloys containing 0·139 wt-% (= $1{\cdot}41\times10^{-3}$ mole fraction) manganese as a function of temperature. Dashed lines give the H_2S/H_2 ratios calculated from published data for the reaction between* pure *manganese and* pure *sulphur using the mole fraction of manganese in the silicon–iron alloys as the manganese activity*

was determined using X-ray emission analysis; again it was observed to be uniform. The explanation therefore does not rest with a non-equilibrium distribution of manganese.

At the highest temperature, 1234°C, both criteria worked perfectly. In addition, there was evident no rise in radioactivity toward the centre of the sheet in those specimens that were equilibrated below the critical H_2S/H_2 ratio. This high-temperature series also permitted an accurate determination of the linear plot of H_2S/H_2 v. radioactivity; Fig.14 gives the result.

The radioactivity corresponding to the critical H_2S/H_2 ratios was related through several chemical analysis cross-checks to percentage sulphur. Repeat runs were made at below critical values of H_2S/H_2, the resulting percentage sulphur extrapolated linearly from the origin to the critical H_2S/H_2 ratio and the percentage sulphur corresponding to saturation read off. The results were consistent; the values for solubility product are plotted in Fig.15 along with the two points for the MnS solubility in γ-iron as determined by Turkdogan *et al.*[9] The present work gives for the solubility product of manganese and sulphur in 3·25% silicon–iron, the following:

$$\log K_{sp} = \log [\%Mn][\%S] = -\frac{5560}{T} + 0{\cdot}72 \quad (1000\text{–}1250°C)$$

Table IV gives the solubility product at selected temperatures. Turkdogan *et al.*, give the following expression for the solubility product in γ-iron:

$$\log K_{sp} = \frac{-9020}{T} + 2{\cdot}929 \quad (1200 - 1350°C)$$

The agreement between the two empirical expressions is less than perfect, however, the data of Turkdogan *et al.* were determined at high temperatures where the experimental points show fairly good agreement with the present results. In fair support of these results is the work on the manganese–sulphur system by Kapustinski and Korshunov as reported in the summary paper by Richardson and Jeffes.[3] Using their data for the reaction, $2\,MnS + S_2 = 2\,MnS$, and the data for reaction (1), one is able to compute the equilibrium for the reaction, $Mn + H_2S = MnS + H_2$, which is:

$$K(T) = \frac{a[Mn\,S]\,p[H_2]}{a[Mn]\,p[H_2S]}$$

For constant a[MnS] and a[Mn], the temperature of the reaction determines the ratio H_2S/H_2. If we substitute for a[Mn], $1{\cdot}41 \times 10^{-3}$, that is, the mole fraction of manganese in the silicon–iron alloys, and assume that MnS has unit activity, there results a curve of H_2S/H_2 *v.* temperature. This curve is plotted in Fig.16 along with the critical ratios of H_2S/H_2 determined independently for MnS formation in the silicon–iron alloys. The agreement is not bad even though the two standard states of manganese that are represented differ in regard to crystal structure.

SUMMARY AND CONCLUSIONS

1. The bulk diffusion coefficient of sulphur in pure 3·25% silicon–iron (bcc) was measured using a tracer technique to be:

$$D = 2{\cdot}68 \exp[-49\,700/\boldsymbol{R}T] \quad (900\text{–}1300°C)$$

Grain-boundary diffusion was observed on autoradiographs at temperatures as high as 1000°C, but the grain-boundary diffusion coefficient could not be calculated.

2. The bulk-diffusion coefficient of sulphur in single crystals of pure α-iron was measured to be:

$$D = 1{\cdot}68 \exp[-48\,900/\boldsymbol{R}T] \quad (750\text{–}900°C)$$

In addition, fast grain-boundary diffusion was evident in pure iron polycrystals at all temperatures in the α-range.

3. The solubility of sulphur in pure α-iron of grain size 0·11 ±0·02 mm was measured to be:

$$\%\underline{S}_{max} = 7{\cdot}85 \times 10^3 \exp[-28\,900/\boldsymbol{R}T] \quad (650\text{–}910°C)$$

or

$$\log (\%\underline{S}_{max} = \frac{-6320}{T} + 3{\cdot}89$$

4. Sulphur solubility in pure 3·25% silicon–iron was measured as a function of temperature (*see* Figs.9 and 10). The plot is non-linear.

5. The solubility product of sulphur and manganese in 3·25% silicon–iron was measured to be:

$$[\%\underline{Mn}][\%\underline{S}] = 5{\cdot}25 \exp[-25450/\boldsymbol{R}T] \text{ or}$$

$$\log\{[\%\underline{Mn}][\%\underline{S}]\} = \frac{-5560}{T} + 0{\cdot}72 \quad (1000\text{–}1250°C)$$

ACKNOWLEDGMENTS

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Sinter-plant assessment trials at Barrow Ironworks Ltd

D. F. Ball

SYNOPSIS

An assessment trial has been carried out on the Dwight–Lloyd sinter strand recently commissioned at Barrow ironworks. This plant contains several new features, the most notable of which is the facility for using preheated air for sintering after ignition; in addition to this the plant is fitted with constant-weight feeders for controlling raw material input rates, quenching trommel for cooling the return fines, and a Davidson cellular-type dust collector. The experiments were designed to exhibit the effect of operating with and without preheated air after ignition, and with and without limestone fines in the mix. Particular attention has been given to the measurement of waste-gas flow and leakage. Assessments of the performance of the cooler and quenching trommel have been made.

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INTRODUCTION

IN CONTINUATION of the policy of assessing sinter plants with interesting features[1–4] tests have been carried out at the sinter plant of Barrow Ironworks. This plant contains several innovations, the most notable being the facility for using preheated air for sintering after ignition. In addition the plant is fitted with constant-weight feeders for controlling raw mix, flue dust, and coke input rates, a quenching trommel for cooling the return fines, a Davidson cellular-type dust collector, and a tube fitted into the wind-box main for withdrawing dust-laden gases from the discharge-end hood.

At the time of the trial, iron demand was such that the sinter plant was only operating five 8-h shifts/week and assessments were made over periods of roughly 6 h during ten consecutive shifts. The plant was operated normally, such variables as mix composition and strand speed being controlled by the operator. The experiments were designed so as to exhibit the effect of operating essentially with and without preheated air after ignition and with and without limestone fines in the mix. To facilitate this it was agreed before the trial began to maintain the ore mix composition virtually unaltered throughout the trial. Throughout the trial the team enjoyed the fullest co-operation from the management and operators and also the services of the company's laboratory, electrical, and fitting shops.

DESCRIPTION OF THE PLANT

Sinter machine

The sinter plant at Barrow Ironworks is a single continuous strand built by Huntington Heberlein and Co. Ltd. Commissioning of the plant began in November 1957 and by February 1958 the plant was running at essentially design rating. Figure 1 shows a diagrammatic arrangement of the plant layout. The strand is 6 ft wide with an effective length of 127·5 ft divided into 20 windboxes and giving a grate area of 765 ft^2. Each windbox is fitted with a slide valve so that if necessary at any stage of sintering the suction can be reduced. The strand is made up of 161 pallets 6 ft wide and 2 ft long fitted with drop-bar seals. The maximum bed height which can be obtained is 14 in. and the strand speed is nominally controllable between 3 and 12 ft/min. The windlegs are connected to a common constant-velocity waste-gas main leading to a Davidson cellular-type dust collector and then the fan. An efficiency test on the dust collector was conducted by Messrs Davidson and Co. Ltd in the presence of representatives from BISRA and Messrs Simon Carves Ltd. The test was carried out in May 1958 with the sinter plant operating on 50% Granada fines and 50% Sierra Leone fines, and showed that for an inlet dust burden of 0·515 gr/ft^3 (NTP) the outlet dust concentration was 0·079 gr/ft^3 (NTP) and that the collector was operating above the rated efficiency of 82·5%.

The fan is a constant-speed vane-controlled type of backward bladed construction with a design rating of 200000 ft^3/min, and 30 in. wg at 175°C; the horse power required is 1280 at the shaft and the motor horse power 1380.

At the discharge end of the strand the sintered material falls onto a crash deck of steel rails and passes through a sinter breaker on to a manganese steel static grizzley screen; this screen is two thirds $\frac{1}{2}$-in. spacing and one third 1-in. spacing. Oversize material falls on to the forced-draught straight-line cooler (Fig.2), cooling air being supplied by three fans each capable of supplying 60000 ft/min^3 at 2$\frac{1}{2}$ in. wg pressure. Hot air from the first 30 ft of the cooler strand enters a mild-steel hood and is carried by mild-steel ducting through a measuring venturi to a brick-lined arched hood covering the first seven windboxes of the sintering machine. This hood is equipped with blast-furnace gas burners to raise the temperature of the preheated air still further. The cooled sinter falls on to a vibrating screen with $\frac{1}{4}$-in. spacing and the finished sinter is taken by conveyors over a belt weigher to the finished sinter bunker into which it is fed by means of a spiral chute. The undersize from the vibrating screen forms

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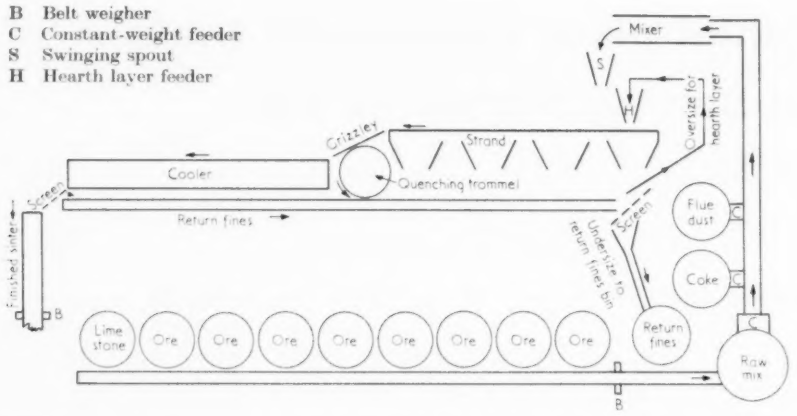


1 *Material flow sheet for Barrow sinter plant*

the start of the return fines return system and provides an effective protection for the rubber belt against any hot fines which might inadvertently fall on to the belt at a later stage.

The hot undersize material from the grizzley at the discharge end is quenched in the return fines trommel mixer and then joins the return fines from the cooler. The whole of the return fines then pass to a vibrating screen with $\frac{3}{8}$-in. apertures, the oversize from which is used as hearth layer. The undersize from this screen then passes to the return fines storage bin of roughly 300 tons capacity.

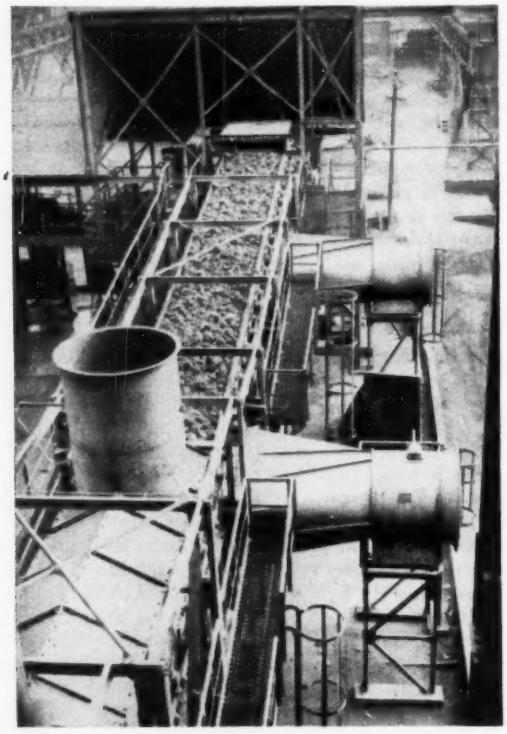
Raw materials

The ore fines and flue dust fall from rail wagons into a track hopper and are fed by an electromagnetic vibrating feeder onto a conveyor-belt system discharging into the ore bunkers.

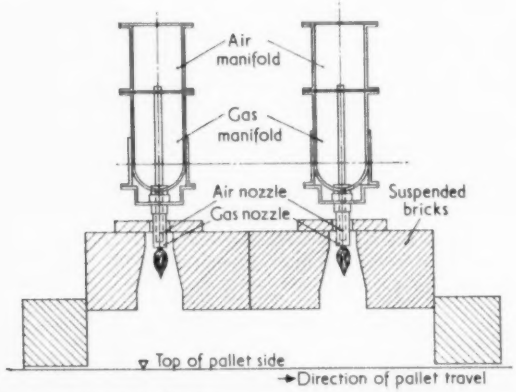
The coke breeze is fed into a rough-coke bin of 100 tons capacity and is fed by a vibrating feeder on to a vibrating screen, of $\frac{1}{8}$-in. nominal aperture, the oversize passing through a rod mill where it is crushed to $-\frac{1}{8}$-in., the crushed product joining the undersize from the screen.

Mixing and feeding

There are ten feeder tables feeding ores, limestone, and return fines on to a single gathering conveyor belt. The speed of the feeder tables can be collectively controlled from the console but individual feed rates are normally adjusted by manually operating an adjustable plough on the table concerned in conjunction with tray weighings. A belt weigher is placed so that it records an integrated ore and limestone weight but excludes the weight of return fines being used. The material from this main gathering belt discharges on to an inclined conveyor which carries this ore mix in an enclosed gantry to a surge bin with an effective capacity of about 15 tons. This surge bin which is fitted with high- and low-level alarm is discharged by means of a feeder table, the speed of which is controlled by a constant-weight feeder. Fine coke breeze and flue dust are discharged from their respective bunkers by constant-weight feeders and travel by inclined conveyor, alongside the ore-mix conveyor, to a chute



2 *Sinter cooler showing two of the three fans*



3 *Arrangement of ignitor*

down which the coke and flue dust fall on to the metered ore mix leaving the surge bin. Collective control can be exercised over these three constant-weight feeders but the device was not in operation at the time of the trial. The materials then enter the sinter building and pass into a trommel type mixer equipped with a paddle shaft. Water addition is made along the length of the mixer by means of fine sprays and is controlled by the sinter machine operator. After mixing, the raw mix is taken by a conveyor to the swinging spout from which it is distributed across the width of the sintering machine, rolling down a cut-off plate which is adjustable for height and angle; the cut-off plate is normally inclined at 81½° to the horizontal.

Ignition and preheated air hood

The ignitor shown in Fig.3 consists of two rows of 16 jets located between rows of suspended bricks. The ignitor burns blast-furnace gas giving an ignition intensity of 4000 Btu/ft²/min, this gives an effective ignition time of 48 s and provides each square foot of moving bed surface with 3200 Btu. This produces an excellent ignition giving rise to a hard well-bonded surface free from any loose material. Air to the ignition hood is supplied by a fan and the air/gas ratio at the burner is about 0·6 to 0·65 which is just below the theoretical air requirement. It was noted during the trial that the permeability of the bed under the ignitor is insufficient to permit the waste products of combustion being drawn completely into the bed while under the ignitor. This results in a very small fraction of the heat input being lost but excludes secondary air indicating that ignition is occurring under substantially inert conditions.

Hot air abstracted from the first 30 ft of the cooler is carried by mild-steel ducting, in which a measuring venturi is fitted, to an arched hood covering the first seven windboxes of the sintering machine. A proportion of this hot air can be vented to atmosphere if desired. Provision is made for further preheating of the air by means of blast-furnace gas; this gas is burnt with a lazy flame in the preheat hood, care being taken to ensure that the flame does not impinge upon the sinter bed. Total gas and ignition gas are metered and the amount of blast-furnace gas used for preheat is found by difference.

Plant controls

All control switches for stopping and starting the strand, conveyor belts, feeder tables, cooler, etc. are situated in a control cabin on the strand floor together with all the plant instruments which are grouped together on a panel alongside the control switches. The servo-assisted control lever for operating the fan vanes is situated on the control-switch panel.

Plant instrumentation

1. Suctions at each windleg and at the fan inlet are shown on vertical water gauges.
2. The temperature of no.20 windbox is indicated and the temperature in even-numbered windlegs plus nos.17 and 19 is recorded.
3. Strand speed and cooling strand speed are indicated in ft/min.
4. Total blast-furnace gas flow and gas flow to the ignitor are recorded and the gas used is integrated.
5. The sinter plant fan current consumption is indicated in amperes.
6. As a guide to bed permeability the waste-gas volume passing through no.5 windbox is recorded but this gauge was not in operation during the period of the trial.
7. The flow rate and temperature of gas at the fan are indicated and recorded; the fan-gas flow is registered by measuring the pressure loss across a length of ducting between the fan outlet and the stack; in the absence of a venturi for measuring fan-gas flow, calibration of a section of main or of a dustcatcher does, in fact, provide a convenient method of measurement for plant control.
8. The quantity of water to the final mixer and quenching trommel is indicated in gal/h.
9. The feed rates of coke, flue dust, mixed ores, and mixed ores with return fines are shown on the control panel. The daily consumptions are available to the management from the ore weighers and constant-weight feeder integrators which are duplicated at the control panel. The finished sinter make is integrated, indicated, and recorded.
10. The pressure under the cooler grate and the air flow and temperature of the preheated air from the cooler to the sinter strand are indicated and recorded.

TRIAL CONDITIONS AND MEASUREMENTS

It was agreed that during the assessment trial the ore mix used should remain substantially unaltered. Adjustments to strand speed, coke content, circulating load, etc. were substantially uninfluenced by the trials team and as a result of single shift operation the operating personnel remained unchanged throughout the trial. Measurements of the following variables were made at the time intervals shown.

Frequency	*Variable*
Every 10 min	Fan gas volume, ft³/min (STP)
	Fan temperature, °C
	Fan suction, in. wg
	Fan current consumption, A
	Fan vane position
	Windleg suctions, in. wg
	Raw mix, coke, and flue dust input rate, tons/h
	Hottest windbox no.
	Strand speed, ft/min
	Ignition gas flow, ft³/min
	Total blast-furnace gas flow, ft³/min
	Preheater air volume, ft³/min
	Preheater air temperature, °C
Every hour	Finished sinter make, tons
	Finished sinter temperature, °C
	Finished sinter size grading
	Return fines temperature, °C
	Return fines size grading (made)
	Return fines size grading (input)
	Ore input to surge bin, tons
	Coke ash and moisture, %
	Raw mix moisture, %
	Cooler speed, ft/min
	Air volume to ignition hood, ft³/min
	Proportions of ore, limestone, and return fines

Once per assessment (average sample)	Coke, flue dust, and return fines size grading: sinter analysis
Once during the trial	Ore, flue dust, and limestone analysis and size grading
Several times during most assessments	Segregation on the strand

EXPERIMENTAL PROCEDURE

Measurement of gas flow

The fan-gas flow is measured from the pressure loss across a length of duct connecting the fan to the exit chimney. This instrument had been previously set by determining the gas flow with a pitot tube and about three weeks before the trial was checked during a period of steady operation; the fan-gas flow as determined by pitot measurement was found to be within 2% of the indicated reading on the instrument. This was repeated with the plant operating cold and substantially the same result obtained. This instrument is calibrated to give the correct reading when operating at 30 in. Hg pressure and 177°C and it is necessary to correct the instrument should the suction and temperature be different from the calibration. The accuracy of this instrument does depend upon the accuracy of pitot determinations in a short length of rectangular duct of diminishing cross-section and it was in fact found that the air-flow was unevenly distributed across the duct; under these conditions it seems doubtful whether an accuracy of better than 5% can be expected.

Temperatures and suctions

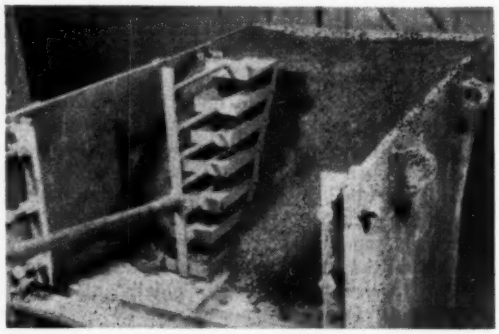
These were obtained from the plant instruments. The strand floor temperature and the dust exhaust duct temperature, both of which are of importance in calculating the leakage, were measured from time to time with a thermometer.

Mix composition and input to the strand

Hourly readings of the feed rate from each feeder table were obtained by placing a tray on the gathering belt and allowing it to pass under the feeder tables concerned. From the individual feed rates the proportion of each constituent in the mix was calculated. A sample of each ore was size analysed for the whole trial, but return fines size grading was determined hourly; the coke size and, during the second week, flue-dust size grading were determined daily. The flue dust-ore ratio was controlled by the operators and maintained at the desired ratio by the constant-weight feeders; readings of these were taken every 10 min in the control cabin. At the beginning and end of each assessment and at hourly intervals throughout, integrated readings of the constant-weight feeders and the ore and sinter belt weighers were taken.

Strand and cooler speed

These were indicated in ft/min in the control cabin and readings taken every 10 min. The strand speed indicator was checked by stopwatch and found to be correct.



4 *Multishovel for taking segregation samples being used on experimental sinter box*

Segregation of raw mix on the strand

A specially constructed multishovel (Fig.4) was used to take samples simultaneously from seven vertical levels in the bed. The samples were then sieved at ¼ in. and selected samples analysed for carbon and lime content.

Moisture content

The moisture content of the raw mix and coke was determined hourly. The coke breeze used is screenings from consignments of purchased Durham and Yorkshire coke and is subject to considerable variation in carbon. To take account of this the moisture and ash content of the coke were determined hourly. It was considered that variation in flue dust composition would not significantly affect the carbon content of the raw mix, but samples for analysis were taken hourly during the second week of the trial.

OBSERVATIONS AND RESULTS

Average conditions observed during the assessment are shown in Table I; derived data have been calculated from the basic equations:

(i) Specific waste-gas volume $v=\frac{60F}{I}\text{ft}^3$

(ii) Permeability $P=\frac{F}{A}\left(\frac{h}{s}\right)^{0\cdot6}$ Bpu

where F = waste-gas flow ft³/min at 60°F and 30 in. Hg

A = effective area of strand, ft²

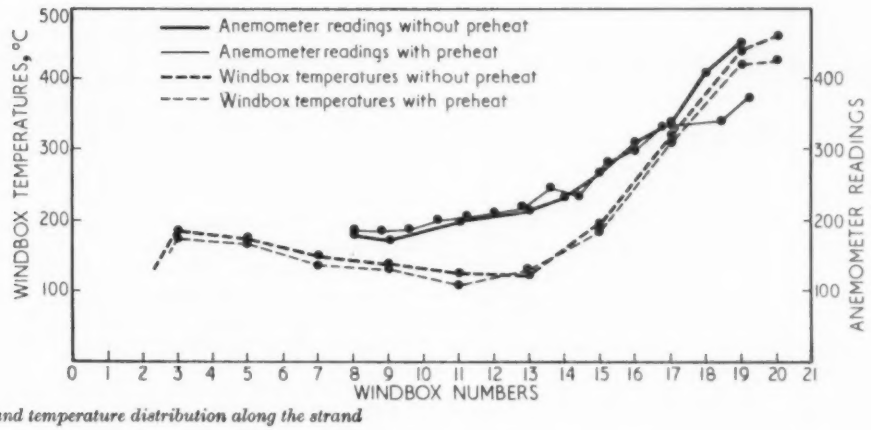
I = material input rate (raw mix), tons/h

h = depth of bed before ignition, in.

s = suction, in. wg

Strand utilization

The practice at Barrow is to use the entire strand for sintering; normally there are no cooling windboxes and strand utilization is 100%. Fluctuations in mix compositions, permeability, and feed rate are small due to the excellent control which constant-weight feeders allow; it is, however, possible that for short periods of time a little unsintered material could have been discharged from the end of the strand. Visual observation indicated that by the end of the strand sintering was just complete. With permeable mixes which would have sintered before the end resulting in some cooling on the strand the normal practice was partially to close the slide valves on the last two windboxes. The



5 *Airflow and temperature distribution along the strand*

windbox temperatures are recorded and the figures from the charts have been averaged for the first part of the assessment without preheat and the second part with preheat, it can be seen from Fig.5 that the temperature distribution along the strand is similar in both cases. It is interesting to note the rather high temperature in the first windboxes, this is probably due to the effect of the hot grate bars and hearth layer. Anemometer readings have been taken along the strand after the preheat hood and average values of these for the two weeks are also shown in Fig.5; while it is not generally possible to use devices above the strand to give absolute measurements of airflow this provides a reasonable method of comparison; the airflow through the bed after the hood is similar in both weeks, that is with and without preheat suggesting that the decrease in permeability when using preheat (to be referred to later) is due to a decrease in bed airflow in that section of the strand under the preheat hood.

Specific waste-gas volume

Since generally the whole strand has been used for sintering no correction for cooling on the strand is necessary. The total gas flow at the fan has been used to determine the quantity termed 'fan waste gas/ton'. This is the volume of waste gas at the fan per ton of raw mix fed to the strand. Tests to determine plant leakage in relation to strand suction have made it possible to calculate a figure for the actual gas flow through the bed and thus determine the specific volume, termed 'bed waste gas' per ton of raw mix. Table I shows the fan waste gas and bed waste gas/ton for the four stages of the assessment trial. The fan volume/ton varies throughout the assessments between 50800 ft^3 and 62400 ft^3 (STP). Values for the bed waste gas/ton which excludes the leakage show a variation between 23000 ft^3 and 27400 ft^3. The addition of limestone to the sinter mix and the use of preheated air have no significant effect upon the bed waste-gas requirements. Over the ten assessments of average duration 5 h 20 min the average bed waste gas per ton of raw mix was 24900 ft^3 (STP). It is considered that with the techniques involved and the assumptions made in calculating this value an accuracy of $\pm 10\%$ could be expected.

Use of preheated air

As has been previously described, air from the first third of the cooler re-enters the bed over the first seven windboxes. The temperature of this air leaving the cooler varies between 100° and 200°C, the average temperature during the first week being 155°C and during the second week 125°C. The preheat air volume was 10000 ft^3 (STP)/min and if all this volume was used for sintering, it would constitute a heat input of about 0·4 therms/ton of finished sinter in the first week and 0·35 therms/ton of finished sinter during the second week.

During the second week the warm air from the cooler was further heated by burning blast-furnace gas. It is reasonable to believe that satisfactory sintering will not take place with coke breeze if the oxygen content of the gases entering the bed is below 15%. A reduction in oxygen content below this value would result in serious 'mismatching' of the heat and flame fronts and an increase in the specific waste-gas volume.[5] The maximum temperature which can be obtained by burning blast-furnace gas in hot air at 125°C such that the waste gases contain 15%O_2 is 600°C. If waste gases preheated to this temperature form a quarter of the sintering air used, then if thermal interchangeability with 100% efficiency is possible, the maximum reduction in coke breeze consumption per ton of blast-furnace sinter is 0·25 cwt. There is no information available to suggest that the use of preheated air after ignition will, for foreign ores, reduce the thermal requirement of the process and data obtained from box tests indicate that with some ores replacement of coke by preheated air would be thermally inefficient.

The average preheat air temperature taken by thermocouples under the hood during the second week of the trial was 550°C and there was little variation in the temperature along the length of the hood. The gas composition under the hood was determined twice per assessment, the average analysis being 5·8%CO_2–15·2%O_2. When preheating the air to 550°C the original plant output could not be maintained and the average sinter make fell from 74 to 64 tons/h, together with a similar reduction in input rate of raw mix. This was due in the main to a decrease in bed gas flow without a change in specific waste-gas volume. Figure 5 shows that the bed gas flow after the preheat hood is the same for both weeks of the trial and this indicates that all the reduction in bed gas flow must occur under the preheat hood. The average bed gas flow during the

TABLE I Average conditions observed during assessment

Assessment No.	Lime-stone, %	Ores, %	Return fines, %	Moisture in raw mix, %	Input rate, ores, limestone, return fines), coke, tons/h	Input rate flue dust, tons/h	Fan volume, ft³/min. × 10³	Average suction, in.wg.	Leakage volume, ft³/min. × 10³	Output finished sinter, tons/h	Heat input, therms/ton sinter: Coke	Flue dust	Ignition	Blast-furnace gas preheat	Hot air from cooler	Total	Temp., °C: Sinter from cooler	Return fines from trommel	Fan air/ton, ft³	Air/ton raw mix, ft³	Time on strand, min	Average sintering Performability, BPU	Finished sinter size, +2	+1	+½	−½	Strength Index
1	5·2	5·5	4·3	8·0	13·3	6·6	13·1	30·1	7·0	7·2	23·1	2·3	1·4	…	0·4	27·2	112	132	54 400	25 400	14·7	45	29	28	22	16	5
2	5·2	5·7	4·2	7·6	13·5	6·50	13·1	29·6	6·9	7·4	21·4	2·3	1·3	…	0·4	25·4	129	136	53 500	25 300	14·6	45	23	20	21	27	9	62
3	5·3	5·5	4·1	7·6	13·5	6·63	12·7	28·9	6·8	7·4	22·2	2·3	1·4	…	0·4	26·3	162	143	51 700	24 000	14·6	44	21	25	24	22	8
4	5·7	…	4·3	8·6	13·4	6·83	12·7	29·6	6·9	7·6	22·5	2·3	1·4	…	0·4	26·6	152	157	51 900	23 500	14·7	42	23	24	22	22	9	63
5	6·1	…	3·9	7·9	13·4	7·20	12·4	28·9	6·8	7·3	24·4	2·3	1·4	…	0·4	28·5	105	119	50 800	23 000	14·6	42	24	23	23	21	9
6	6·0	…	4·0	7·6	10·9	5·00	4·2	12·3	29·6	6·9	6·4	21·2	2·0	1·3	2·1	0·3	26·9	156	127	62 400	27 400	17·3	40	22	23	23	20	12	60
7	6·0	…	4·0	8·8	10·9	5·38	4·2	12·1	29·7	6·9	6·5	21·3	1·9	1·4	2·3	0·3	27·2	106	114	61 100	26 300	17·8	38	22	25	22	20	11
8	5·7	6·0	3·7	8·0	12·1	5·72	5·0	12·3	28·6	6·8	6·5	22·6	2·3	1·3	2·2	0·3	28·7	107	126	56 200	25 100	16·4	41	25	21	22	22	10	53
9	5·6	6·0	3·7	8·0	11·9	5·87	5·0	12·2	30·0	7·0	6·2	23·5	2·4	1·3	2·3	0·3	29·8	112	158	56 200	24 000	16·9	38	18	22	24	25	11
10	5·4	6·4	4·1	7·9	11·7	5·50	4·2	12·3	29·6	6·9	6·4	21·4	2·0	1·3	1·8	0·3	26·8	116	104	58 300	25 600	17·3	41	23	22	22	22	11

Bed height 11½ in. Strand area 765 ft². Final windbox normally hottest.

first and second week is 58500 and 53000 ft³/min, and assuming the fraction of air entering the bed under the preheat hood during the first week is between a quarter and a third of the bed air, it can be shown that for the second week the air volume entering the bed under the hood is from 62 to 69% of the figure for the first week. Any increase in bed or air temperature would of course be expected to reduce permeability and air flow.

Table I shows that the use of preheat results in some deterioration in sinter size grading, the +2-in. fraction falling from 24 to 22% and the −¼-in. fraction increasing from roughly 8 to 11%. The strength of a composite sample of finished sinter has been determined by the modified drop test method[6] and this shows that the strength index of the finished sinter deteriorated with the use of preheat; this being more marked when limestone was added.

Average thermal requirements per ton of sinter for the four sets of conditions from Table I, column 18, are as follows:

		Total heat input, therms/ton sinter
Normal mix	No preheat	27·6
	Preheat	27·1
Limestone added	No preheat	26·3
	Preheat	28·4

For the normal mix, then, the additional 2·2 therms supplied by gas resulted in a saving of 2·55 therms in the form of coke and flue dust. Making some allowance for the deterioration in strength index it may be said that the preheat is equivalent to coke, therm for therm.

In the series when limestone was added, the picture is quite different, there being no saving in coke compared with the period without gas preheat.

It must be concluded from these results that with the ore mix in use at the time of the assessment, the use of blast-furnace gas to preheat the air entering the bed during the first third of the sintering time resulted in a decrease in sinter output, a decrease in sinter strength and a coke saving equivalent on a heat basis to the gas consumed. The trials with limestone showed no coke saving. However, experience in the use of preheated air at the time of the trial was limited to a few weeks duration and to what extent these results could be improved by further experience is, as yet, unknown. For example, the high degree of coke segregation observed is admirable for sintering with cold air, but whether coke segregation to this extent is necessary when sintering with preheated air seems doubtful and it may very well be that this is one of the factors affecting the utilization of preheat.

Effect of limestone additions to the sinter mix

It can be seen from Table I that limestone additions have no significant effect upon the permeability or air requirements of the sinter mix. When sintering without preheat the strength index is unaffected by limestone additions but when using preheat there is a decrease in strength when adding limestone to the mix.

The limestone added gave an average lime/silica ratio in the finished sinter of 0·93 and analysis shows that the sulphur content of the finished sinter, which varied between 0·006 and 0·016%, was about doubled on average when limestone was added to the mix. Analyses of finished sinter are given in Table II; the

mean total iron content with and without limestone additions was 56·0 and 59·9% and the ferrous iron content 9·1 and 13·3%, respectively, thus limestone additions increase the degree of oxidation. While the addition of limestone does not decrease sinter output, the lower iron content in the finished sinter results in a decrease in iron throughput of about 7%. The finished sinter during assessments 4–7 contains a decreasing quantity of lime and this is evidently due to contamination by residual return fines from the first series.

Plant leakage

With the strand sealed with stout paper the leakage of air into the plant was measured at varying suctions within the operating range. The strand was completely covered with 3-ft wide strips of brown paper, three strips being laid the full length of the strand, this provided generous overlaps so that when the suction was applied a good seal was obtained. This leakage was determined with the dust extraction main in both the closed and open position. The results obtained show that the leakage airflow is given by the following

$$L_T = L_S + L_D = 12\,700\sqrt{S} + 80\sqrt{S}$$

where L_T = total leakage
L_S = strand leakage
L_D = dust extraction tube leakage
S = strand suction

It is true, however, that the leakage air temperature is considerably higher during plant operation than under the cold conditions of the leakage tests. The temperature in the dust extraction tube has been found to be about 230°C and the average temperature of the strand leakage air measured by moving a thermometer along the strand in the vicinity of the drop bars has been estimated as 40°C for operation without preheat and 50°C during the second week when preheat was being used. An added complication is that the suction in windboxes 19 and 20 is often considerably lower than windboxes 1–18; to allow for this the strand leakage has been apportioned to each section of the strand in direct proportion to the peripheral length associated with this section; however, this correction only normally affects the leakage volume by about 1%. These two corrections give rise to the following equation which has been used in determining the leakage at the fan, L_T.

$$L_T = 11\,200\sqrt{\frac{288S_{1-18}}{\theta_S}} + 600\sqrt{\frac{288S_{19}}{\theta_S}} + 900\sqrt{\frac{288S_{20}}{\theta_S}} + 800\sqrt{\frac{288S_{1-20}}{\theta_D}}$$

where S_{1-18} = average suction for windboxes 1–18, in. wg.
S_{19} = suction in windbox 19, in. wg
S_{20} = suction in windbox 20, in. wg
θ_S = average strand floor temperature in vicinity of drop seal bars, °A
θ_D = dust extraction tube temperature, °A.

No attempt was made before the leakage test to ensure that the drop bars had fallen into place and it is considered that the leakage constant is representative of continuous operation. During actual operation the number of drop bars failing to fall into position were counted and in all cases were found to exceed 15%. It

TABLE II Size and chemical analyses of ores, sinters, return fines, coke, limestone, etc. during Barrow trial

Assessment No.	Return fines from cooler and quenching trommel (including hearth layer), in.				Return fines from bunker (excluding hearth layer), in.				Coke size analysis, in.				Flue dust analysis, in.				Chemical analysis finished sinter, %			
	+½	−½+¼	−¼+⅛	−⅛	+½	−½+¼	−¼+⅛	−⅛	+⅛	−⅛	30–44 mesh	44–60 mesh	60–85 mesh	85–100 mesh	−100 mesh	+⅛	−⅛	−⅛	Total iron	Ferrous iron
1	8	34	39	19	33	41	26		5	30	65								56·7	10·8
2	8	33	38	21	29	43	28		6	29	65								56·2	9·4
3	7	36	38	19	22	41	37		8	31	61								55·4	8·6
4	9	38	32	21	24	40	36		8	33	59								59·2	12·1
5	10	37	31	22	31	36	33		9	27	64								59·8	13·5
6	9	36	31	24	29	34	37		6	27	67								60·2	13·9
7	9	27	34	30	33	35	37		6	25	75								60·4	13·6
8	7	34	34	25	28	35	37		0	25	75								56·5	9·3
9	8	30	28	34	34	28	28		0	25	75								55·7	9·6
10	7	28	35	30	34	27	39		6	24	70								55·9	7·0

	+½ in.	½–¾ in.	¾–1 in.	1–1½ in.	1½–2 in.	⅜–30 mesh	30–44 mesh	44–60 mesh	60–85 mesh	85–100 mesh	−100 mesh	Total iron	Ferrous iron	Lime	Silica	Sulphur	Loss on ignition
Granada	0	4	19	27	29	7	2	2	2	1	7	56·9	0·2	3·4	4·3	0·008	6·80
Quenza	0	5	16	24	31	11	1	1	2	0	9	54·8	0·2	5·2	3·3	0·044	8·40
Sierra Leone fines	0	1	3	10	37	8	10	11	10	2	8	57·0	0·2	0·1	9·1	0·017	3·50

	5–10 mesh	10–30 mesh	30–44 mesh	44–60 mesh	60–85 mesh	85–100 mesh	−100 mesh	Total iron	Ferrous iron	Lime	Silica	Sulphur	Loss on ignition
Limestone Assessments, 1–3	8	20	52	2	1	3	14	0·3	Nil	51·8	3·2	0·008	41·6
Limestone Assessments, 9–10	4	14	16	15	20	5	26	0·2	Nil	52·0	2·7	0·018	42·1

is interesting to compare the leakage constant per foot of periphery with the figure found during the previous major assessment at Shotton. For a periphery of 252 ft at Shotton the leakage constant was 11400, i.e. 45·3 per ft of periphery and for Barrow with a periphery of 267 ft. the leakage constant is 12700, i.e. 47·6 per ft.

Bed segregation

The desirability of bed segregation has been mentioned in previous assessment reports[1,3,4] and a quantitative measure of the degree of segregation has been suggested.[4] Tests were carried out with a multi-shovel, Fig.4, to determine the size segregation of the raw mix. Samples were taken simultaneously at seven vertical levels above the hearth layer, the top sample being above the height of the cut-off plate. The results have been averaged for the whole of the trial and the %+¼-in. material, the carbon content, and, where applicable, the lime content at the seven levels are shown in Table III. The amount of +¼-in. material varied from 14·7% at the top of the bed to 20·0% at the bottom, while carbon varied from 4·6% at the top to 2·5% at the bottom. There was no evidence of limestone segregation in the bed.

TABLE III Bed segregation

Level	Size, carbon+lime segregation +¼ in., %	CaO, %	C, %
Top	14·7	8·5	4·6
2	15·3	8·5	3·9
3	15·8	7·9	4·0
4	16·8	9·3	3·0
5	17·8	8·0	3·0
6	18·6	7·7	3·3
Bottom	20·0	8·4	2·5
Segregation index	+3·0	0	−4·9

Note: The 'segregation index' used above is derived as follows, when considering size segregation, the amount of segregation occurring in a sinter bed may be looked on as a function, first, of the amount of oversize (in this case +¼ in.) present in each layer of the bed and, second, of the distance of these particles from that position which they would occupy in a homogeneous bed. A useful measure of the amount of segregation would therefore be the product of these two factors (say Z). For a bed height h containing an average oversize fraction ϕ if the excess or deficit of oversize at different levels x from the band of zero segregation is y, it can be shown that

$$Z = \sum_{-a}^{h-a} yx\delta x$$

where a is the distance of the band of no segregation from the top of the bed. The value of Z is dependent on the average concentration of the oversize fraction in the bed and upon the numerical value of h. To minimize this effect, Z has been calculated for the average oversize fraction numerically equal to 100 and for a bed height of unity.

A similar definition applies when considering segregation of a particular chemical constituent, e.g. CaO or C.

Sinter cooling

The hot sinter leaving the strand passes over a grizzley screen which removes the return fines and hearth layer. The oversize enters a straight-line cooler, the cooler being designed to reduce the finished sinter temperature so that it can be transported by rubber belt conveyors. The cooling air is supplied by three fans each capable of supplying 60000 ft³/min at 3·4 in. wg pressure and driven by 45 hp motors. The cooler was originally fitted with a rubber seal to prevent cold air escaping from between the pallets and the rails on which the pallets run; this rubber seal had failed and it was observed that the leakage as a result of this was appreciable. It is understood that this fault has since been rectified.

Sinter samples were taken hourly from the end of the cooler and the sinter temperature was determined by using a large calorimeter insulated with slag wool. The average finished sinter temperature was found to be 120–130°C. Since clearly the heat in the finished sinter is considerably segregated between the different sizes of material, tests were carried out on the +2-in. fraction of the finished sinter and these showed that average temperature of this fraction of the material was 230°C. Individual lumps of sinter up to 1 ft in size gave temperatures of between 350° and 650°C. The only possible technique for taking sinter samples at the inlet end of the cooler would have involved manipulating a shovel in a confined space to catch pieces of the hot sinter; it was considered that this method of collecting the material was unsafe and furthermore it is very doubtful whether a reasonably representative sample could be obtained by this means. A heat balance indicated that the average sinter temperature was from 500° to 600°C before the cooler. It seems likely, however, that since the top of the bed produces more return fines then the temperature of the material going on to the cooler will be higher than the temperature of the return fines entering the quenching trommel.

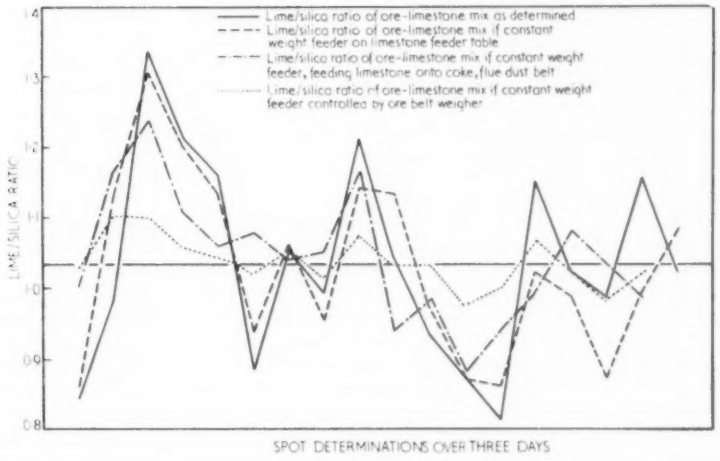
The temperature of the return fines on the return fines belt from the cooler and the quenching trommel has been determined in a similar manner to the temperature of the finished sinter. The average return-fines temperature was found to be about 130°C, these return fines are made up of two parts, those from the cooler which constitute roughly a sixth of the total under normal operation and a quarter when operating with preheat, and those from the return fines quenching trommel. It is the return fines from the quenching trommel which contain the hearth layer and at times it was observed that this larger material was inadequately quenched. This hot material does, however, fall on to a belt protected by cold fines from the cooler.

Hearth layer and return fines

The return fines both in the raw mix and on the return fines return belt were sampled every hour. The average size analysis for each assessment is shown in Table II. On two occasions the belt system was stopped so that the amount of return fines from the cooler could be determined. Without preheat it was found that the return fines from the cooler constituted roughly 18% of the total returns, and when preheat was being used 28%; too much reliance should not be placed on this data since it was only possible to carry out a single test during each week of the trial.

Constant-weight feeders

Before and during the trial the constant-weight feeders were checked, by stopping the appropriate conveyor belts and weighing the raw mix, coke, or flue dust along a measured length, and found to vary by only ±½%, the raw-mix feeder, however, having a zero error, the determined figure being between 2 and 3% above the indicated figure. The major source of variation of carbon reaching the strand is the variation in coke ash and moisture; during the period of the trial the moisture content of the coke breeze varied from 1·8 to 14·9% and the ash content from 10·2 to 16·8%. The variation in carbon content to the strand resulting from these factors can be apportioned between the


Lime/silica ratio of ore-limestone mix as determined
Lime/silica ratio of ore-limestone mix if constant weight feeder on limestone feeder table
Lime/silica ratio of ore-limestone mix if constant weight feeder, feeding limestone onto coke, flue dust belt
Lime/silica ratio of ore-limestone mix if constant weight feeder controlled by ore belt weigher
LIME/SILICA RATIO
1·4
1·3
1·2
1·1
1·0
0·9
0·8
SPOT DETERMINATIONS OVER THREE DAYS

6 *Variation in lime/silica ratio of ore–limestone mix*

moisture and ash content as 85 and 15%. The introduction of coke-breeze drying, possibly with hot air from the cooler would, besides saving rod milling costs through enabling the breeze to be screened more efficiently, reduce the variation in carbon content in the coke by a factor of six. The water associated with the amount of coke required to make a ton of sinter would require about 0·2 therms for evaporation.

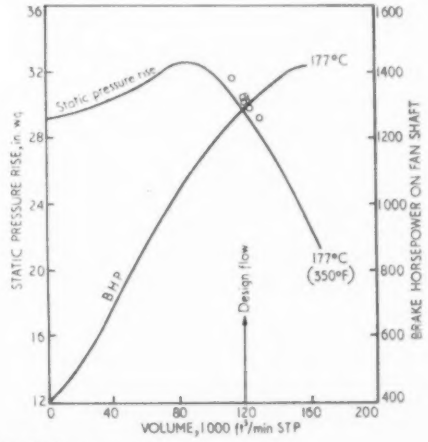
It is interesting to contemplate the effect of fitting a constant-weight feeder to the existing limestone bunker. The resulting limestone could be fed on to the mixed-ore belt or alternatively with suitable engineering modifications on to the coke and flue-dust belt. In the former case residual variations in the lime/silica ratio would mainly be caused by fluctuations in flow from the ore feeder tables, and in the second case variation would be caused by fluctuation in the ore to return fines ratio of the material fed from the raw mix surge bin. Figure 6 shows the lime/silica ratio from 18 spot sample determinations during the first three days of the trial; in the same figure the effect on the lime/silica ratio of incorporating a constant-weight feeder on the limestone bunker is shown. It is clear that to feed a constant stream of limestone on to the mixed-ore belt would result in very little change in the variation in lime/silica ratio; feeding a constant stream of limestone on to the coke and flue-dust conveyor belt would reduce the standard deviation of the lime/silica ratio from 0·16 to 0·12 and the number of spot determinations with a lime/silica ratio greater than 0·2 from the mean would be reduced from 20 to 10%. Since these are only instantaneous readings it is difficult to judge the extent to which the average lime/silica ratio will vary from one blast-furnace skip to another, but with a constant-weight feeder on the limestone and the existing belt weigher on the ore stream it would be relatively simple to calculate the ore and limestone weights entering the blast-furnace sinter bunker. A more satisfactory system, if the engineering difficulties could be overcome with the present layout, would be to vary the belt speed of the constant-weight feeder supplying limestone in proportion to the reading of the ore belt weigher. Thus the amount of limestone added would be proportional to the ore tonnage and the setting of the weigh-length balance. In this case the variation in lime/silica ore ratio would be due to variation in the proportions of each ore in the ore mix. The lime/silica ratio under the circumstances is also shown in Fig.6, the standard deviation of the lime/silica ratio is 0·03 and the number of spot determinations with a lime to silica ratio greater than 0·1 from the mean would be less than 1%. The observed and calculated figures of Fig.6 relate to the ore+limestone in the raw mix. Although variations will also occur in the lime/silica ratio of the return fines, their addition will tend to smooth out the raw mix variations to some extent.

Fan performance

The makers fan curve is shown in Fig.7. Seven periods of about four hours duration have been selected during which the fan vanes were always fully open; the pressure loss across the fan, and the fan airflow and temperature have been averaged for each of these periods and the volume and static pressure rise have been corrected to 177°C. The resultant values of volume and static pressure are shown in Fig.7 and it is considered that these are in satisfactory agreement with the fan curve.

CONCLUSIONS

The assessment trial at the Barrow plant has shown that the bed airflow per ton of raw mix is substantially



7 *Maker's fan curve*

in agreement with figures previously obtained for foreign ore mixes. The average for all assessments is 25000 ft^3 (STP) per ton of raw mix and this is substantially unaltered by the addition of lime stone or the use of preheated air.

The leakage volume was measured, and an expression has been derived for the leakage air at the fan; on this basis the leakage plus some dust extraction constitutes between about 53 and 57% of the fan airflow.

The use of blast-furnace gas to preheat the air entering the first seven windboxes resulted in a decrease in output of from 74 to 64 tons/h and a corresponding decrease in average sintering permeability from 44 to 39 Bpu. For the normal mix, a coke-saving equivalent, on a heat basis, to the gas consumed was obtained. With limestone, however, there was no evidence of coke saving. Experience in the use of preheated air before the assessment trial had been limited to a few weeks, and it is felt that further experience leading to changes in operational technique might well modify the results.

Limestone additions to the sinter mix have had no significant effect upon permeability or air requirements and thus the sinter make has remained unaltered. There is, however, a decrease in iron throughput due to the lower iron content of the sinter when limestone is added. Limestone additions have resulted in a higher sulphur content, a higher degree of oxidation and, when preheated air was used, a lower strength index of the finished sinter.

The constant-weight feeders provide an excellent means of controlling the coke content of the mix to the strand, but their effectiveness is considerably reduced by the variation in carbon content of the coke breeze due to moisture variation. The straight-line sinter cooler reduces the average finished sinter temperature to 120–130°C and the quenching trommel installed has proved equally effective in reducing the temperature of the return fines.

ACKNOWLEDGMENTS

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The BISRA team were fortunate in having throughout the trial the services of Mr A. C. Cowie of Stewarts and Lloyds Limited, Mr M. Leyshon of the Steel Company of Wales, and Dr A. Grieve of Huntington Heberlein Limited; the Ironmaking Division of BISRA is indebted to the companies concerned for this assistance.

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The permissible amounts and use of radioactive cobalt for detecting blast-furnace lining wear

A. Metcalf, B.Sc.

INTRODUCTION

VARIOUS RADIOISOTOPES are used to investigate iron and steelmaking processes. Such investigations are usually completed in a few days and consequently short-lived radioisotopes can be used, and the emitted radiation rapidly decreases to negligible proportions.

However, a few investigations require a much longer-lived radioisotope. In particular, radioactive Co^{60} has been used in several countries to indicate the wear of blast-furnace linings. Since radioactive cobalt only decays to half activity every 5·2 years, the long

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Mr Metcalf was formerly a member of the Ironmaking Division and is now with Plessey Nucleonics, Northampton.

SYNOPSIS

An account is given of the use of Co^{60} in the assessment of blast-furnace lining wear, and the potential resultant contamination of steel is evaluated.

Details are presented of experimental work on the fogging of fast X-ray film by exposure to steel contaminated with Co^{60}. Recommendations are developed as to desirable upper limits of contamination.

It is concluded that contamination of steel should not be allowed to exceed 20 μc/ton and should in addition be restricted to a modest percentage of steel output. 1777

term effects of its radiation emitted from the finished products must be carefully considered. It is generally agreed that the amount of radioactive cobalt permissible in steel has to be limited and several conflicting limits have been put forward. Experiments have been carried out with specially prepared steel containing Co^{60} on the basis of which practical permissible limits are proposed.

THE DETECTION OF BLAST-FURNACE LINING WEAR

The most convenient method of detecting blast-furnace lining wear is to use radioactive Co^{60} pellets. This technique has been described elsewhere[1-3] and serves two main purposes: to give warning of excessive wear and to provide information to aid improvements in lining design. There are two methods of determining when the lining has worn away and released the Co^{60} into the iron. Either the Co^{60} pellet is detected with a portable Geiger counter from outside the furnace shell while it is in place, or it is detected with a scintillation counter in an iron sample taken during casting, after release. The former method is only practicable for pellets less than about 24 in. from the furnace shell. If pellets are placed deeper than this, an iron sample from every cast must be checked for radioactivity. As alternatives, solid rods sonically tested for length and hollow tubes plugged at the outer end when not being probed, have been inserted through the lining. Solid rods tend to erode and bend rather than wear down, and hollow tubes tend to block up with very hard material. A better alternative is to drill a small hole through the lining during bricking and fill it with clay. This can be drilled out, measured and refilled with clay when required. However, it is not always desirable or practicable to do this.

The experience of the last eight years has emphasized the desirability of restricting the use of Co^{60} to those parts of the lining where failures or excessive wear have occurred in previous campaigns or where new designs are being tried. Thus, in the modern blast-furnace, it is considered that pellets in the bosh and slag notch regions are rarely necessary, whereas in the stack, warning pellets of low activity are useful in places where bad wear has previously occurred. In the tap-hole area they have proved valuable in giving warning of break-outs.

MIGRATION OF Co^{60}

In recent years there have been a few occasions when measurable increases in Geiger-counter readings have been observed from pellets in the lower stack region. Detailed investigation showed that a very small fraction of the cobalt had migrated to within an inch of the furnace casing. In this experiment sets of four pellets had been placed one behind the other, each pellet contributing about a quarter to the Geiger-counter reading and the migration effect invalidated the results. In another case migration brought about an appreciable reading after a pellet placed in the middle stack region of a large furnace had, in fact, been lost.

The mechanism of such migration is unknown, but it is thought that, either carbonyl compounds raise the vapour pressure of cobalt sufficiently to cause slight evaporation at the stack inwall temperatures, or under ironmaking conditions cobalt volatilizes slightly, a gaseous sub-oxide or hydroxide possibly being formed. Under normal conditions at the inwall temperature, the evaporation of cobalt is negligible.

It is more important than was at first realized that the Co^{60} should be reliably encapsulated, bearing in mind, however, that when lost as a result of brickwork wear, the capsule must release the cobalt metal in the hearth where it may disperse in the iron.

ESTIMATION OF THE DILUTION OF Co^{60} INTO STEEL

If a Co^{60} pellet enters the iron near the tap-hole shortly before cast time, most of it will appear in that cast, and undergo dilution in some 200 tons of metal, depending on furnace working and furnace size. If a pellet enters the iron remote from the tap-hole well before cast, fairly good mixing will occur both inside the hearth and during outflow and the activity will be spread over more than one cast. This successive dilution of iron in the hearth has been used to estimate the tonnage retained in the hearth at the end of casting.[4]

Contaminated blast-furnace metal is normally transferred to a mixer of 250 to 1000 tons capacity, which is generally kept more than half full of iron and is thus mixed with iron from other casts. Further dilution takes place in the steel furnace where scrap additions amount to as much as 50%.

Estimates of the potential and actual amounts of Co^{60} in steel given in Appendix I are arbitrarily based on the initial activity of single pellets dispersed evenly throughout a tonnage of iron equal to the mixer capacity and subsequently diluted with the appropriate amount of non-active scrap.

The chance of more than one pellet entering the hearth at the same time is remote.

EFFECTS OF RADIOACTIVITY IN STEEL

It has long been recognized that limits must be placed on the quantities of long lived radioisotopes dispersed in steel for general use though agreement has not been reached on the appropriate levels. The various potential hazards are reviewed in the following notes.

Human beings

Typical exposures to potential radiation from contaminated steel which might occur in normal life may be considered as follows:

(i) heavy structural sections in multistorey buildings
(ii) light sections incorporated in furniture
(iii) light sheets in furniture.

The possible effects on the human organism may be considered on the arbitrary basis of 50 μc/ton contamination. As the levels of exposure are so low, they may conveniently be expressed as a proportion of the normal background radiation, noting that the maximum permissible level for continuous exposure permitted by the UKAEA is some hundreds of times background.

(i) the heaviest sections in normal use have a ruling thickness of about 2 in. For the case under consideration the surface of such a section could reach three times background but the provision of the normal brick or concrete encasement would reduce the radiation to a very small fraction of background
(ii) similar conditions would apply at 3 in. distance from a quarter-section such as a bed frame

(iii) an uncovered chair seat $\frac{3}{32}$ in. thick would produce an intensity of about one-quarter background at its surface.

From this it is evident that no harmful effects can arise from steel limited to 50 μc/ton or indeed several times this amount.

Photographic film

The storage of photosensitive materials in steel cabinets or steel reinforced structures involves a danger of damage by radiation from contaminated steel. This effect has previously formed the basis for recommendation on tolerance levels of radiation[1] but reliable experimental data has been lacking, particularly on modern high speed X-ray film.

It was therefore agreed, with the co-operation of Messrs Kodak Ltd, to carry out exposure tests on steel of known Co^{60} content.

Two cwt of steel strip, 0·090 in. thick and a 4-in.sq. ingot were prepared containing 40 μc of Co^{60} per ton. Three other similar-sized ingots were made containing 260, 10, and 2 μc/ton. The activities of the Co^{60} mixed in the steel melt were calibrated against a Harwell standard Co^{60} source known to $\pm 5\%$. A sample of the steel strip was measured in a 4π-counter at Harwell and this agreed with the first calibration to within limits of experimental error.

The steel strip was made into an 18 in.$\times$18 in.$\times$25 in. rectangular cabinet with three equally spaced shelves. Fast X-ray films in heat-sealed envelopes were stored on the bottom and centre shelves and also fixed on the ceiling inside the cabinet. Similar films were also stored at 1 in. distance from 1·5 in. thick, 4 in.sq. sections of the activities mentioned above; this spacing was considered to be the minimum met with in practice.

Samples of the films were developed after 2, 4, and 6 months exposure, the fog density determined and compared with that of 'control' films stored in the same building, but remote from the activity. The fog density was measured in the centre of the films stored above the ingot sections.

The net increase in fogging of the films stored in the cabinet was very similar for all three positions and increased approximately linearly with time. The initial fog density of these fast X-ray films is 0·14 to 0·16 and they are not normally used when the fog density exceeds 0·3. The results of the tests in the 40 μc/ton, 0·090 in. thick cabinet may be summarized as follows:

Type of X-ray film	Net fog density for 6 months exposure		Typical film life, months (density increase 0·15 to 0·3)	
	Due to radiation alone	Normal	Irradiated film	Normal film
Kodirex	0·15	0·09	4	10
Crystallex	0·05	0·03	11	30

The results of the tests with Kodirex films placed 1 in. above 1·55 in. thick, 4 in.sq. ingot sections were:

Concentration of Co^{60}	Net fog density at the film centre due to radiation alone		
μc/ton	2 months	4 months	6 months
260	0·34	0·57	0·68
10	...	0·02	0·03
2	...	0·0	0·0

Earlier work suggested that film placed in contact with metal containing 300 μc of Co^{60}/ton would fog less than twice as rapidly as normal. This conclusion was arrived at by calculation by Voice[1] in this country and experimentally by Bardin and Gruzin[2] in USSR. The present work shows that more stringent limits are required. At the moment it seems unlikely that much faster films will be produced owing to the already short storage life.

Nucleonic instruments

Any increase in the background counting rate of a nucleonic instrument without an increase in counting time will decrease the accuracy of measurement of a radioactive source. The more accurately measurements can be made, the less radioactive tracer need be used and therefore it is important that the background counting rate is kept to a minimum: this applies with particular force in the medical field.

Effect of background on counting errors

The probable error of a measurement, i.e., the error which will be exceeded in 50% of cases, depends on the source strength and background, and on the counting times employed. Putting R_B for the background count and R_S for that due to the measured source and considering equal counting times the relative probable error is given[5] by

$$0{\cdot}67\,[(R_S+R_B)]+R_B{}^{\frac{1}{2}}/R_S$$

As an example, with $R_S=0{\cdot}1\ R_B$ an increase in R_B of 22% would raise the probable error 10%. If $R_S=2{\cdot}5\ R_B$ the same 10% increase in error would not be reached until R_B had increased 47%. Such increased errors could, of course, be compensated for by counting for longer periods.

Experiments have been carried out to assess the effect of contamination of the steel casing of a metal Geiger counter. A beta end-window counter was used mounted in a $1\frac{1}{2}$-in. lead castle and this was exposed to samples of steel containing 44 μc/ton. The results suggested that if the steel case of the counter carried 1 μc/ton, the shielded background would be increased by about 10%. Calculations by Hours[6] suggested a tolerance level for metal Geiger counters of 2 μc/ton which according to the above would increase the background by about 20% and involve an increase of 10% in probable error when counting a specimen with an activity of $\frac{1}{10}$ background.

Highly sensitive instruments

Some nucleonic instruments require all components and shielding to be as free as possible from radioactivity of any kind. In these cases no additional radioactivity can be tolerated and in fact any material used must first be carefully checked for radioactive content. For instance, 1-ft thick steel shielding has been used to enclose a counter to measure the very small amounts of radioactivity present in the human body. Therefore, it is essential that steel be available free from extraneous activity. In this country 84% of the total output has not even been exposed to the risk of contamination and less than one part in a thousand has been contaminated in any way.

PREVIOUSLY SUGGESTED PERMISSIBLE LEVELS

In America in 1954 it was considered safe as far as personnel are concerned to add radioactive tracers in amounts up to 1000 μc/ton to special melts of ferrous metal and other alloys. Also, the USAEC considered that releasing scrap containing less than 4·5 μc of radioisotope per ton would be non-hazardous to sensitive industries.[7]

As mentioned above, a concentration of 300 μc of Co^{60} per ton was found to halve the life of film stored adjacent to it. This limit has been used in UK, USSR, and Germany. In UK no sources larger than 20 mc have been used giving not more than 50 μc of Co^{60} per ton of steel. Similarly in USSR much less than this limit has been used.[2] However, in Germany 150 mc Co^{60} pellets have been used with a hot-metal mixer capacity of 500 tons.

In France it has been proposed that the maximum permissible level should be 2 μc of Co^{60} per ton of steel, which was arrived at as a result of a series of calculations of the effects on nucleonic instruments.[6]

CONCLUSIONS

The use of Co^{60} for the detection of blast-furnace lining wear is valuable for special applications. After detailed consideration of the possibilities of contamination of the products of the iron and steel industry, it is concluded that the technique may well continue to be used subject to appropriate precautions. The pellets should have as low a radioactivity as possible, commensurate with detection outside the furnace shell or in the iron and those placed in the stack should be well sealed to prevent migration of the Co^{60}.

BISRA has not used more than 20 mc sources or allowed final concentrations of more than 50 μc of Co^{60} per ton in the resultant steel. Only a small portion of the steel output can have been affected even to this degree. Such steel does not create any human hazard, but there is some disadvantage in using it to make storage cabinets for the most sensitive X-ray films and it should not be used in the sensitive detectors of nucleonic instruments.

The decrease in the typical life of the fastest X-ray films, stored in cabinets of steel $\frac{1}{16}$ and $\frac{1}{8}$ in. thick and containing 50 μc of Co^{60} per ton, may amount to 25 and 50%, respectively, where the film is in immediate proximity to the metal. In practice these films would probably only be exposed to radiation for part of their life, but it is considered that a maximum level of 20 μc/ton is preferable. In this case the life of X-ray film in a cabinet would be reduced by 10% adjacent to $\frac{1}{16}$ in. metal or 20% where the metal thickness was $\frac{1}{8}$ in.

If steel is used in the manufacture of metal Geiger counters it must contain less than 2 to 3 μc of Co^{60} per ton, otherwise their radioactive background will be increased by more than 20%. If steel or any other material is to be used in special highly sensitive instruments the radioactive content must be as low as possible and no added radioactivity can be tolerated.

RECOMMENDED MAXIMUM PERMISSIBLE AMOUNTS OF Co^{60} IN STEEL

It is recommended that the maximum permissible amount of Co^{60} in steel be set at 20 μc/ton, provided that a large proportion of the steel output can be guaranteed free from Co^{60}, and that steel for the sensitive parts of nucleonic instruments is taken from this portion or checked for radioactivity before use.

ACKNOWLEDGMENTS

The author wishes to acknowledge the generous assistance given to him by his colleagues and many people connected with several blast-furnace plants. His thanks are also due to Messrs Kodak Ltd for making the film tests possible, to their Dr R. H. Herz for carrying out these tests, and to Dr R. A. Allen of AERE Harwell for verifying the radioactive content of the steel strip.

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APPENDIX I

Potential and actual concentrations of steel by Co^{60}

Investigations of blast-furnace lining wear using Co^{60} in this country have been carried out mainly by BISRA. The following estimates of potential and actual contamination of steel by Co^{60} are based on the assumptions outlined in the section dealing with the dilution of Co^{60} in the steel.

Percentages of steel output containing Co^{60} in μc/ton

	More than 50	More than 20	More than 2	More than 0·1
Potential contamination over 5 years	Nil	0·01	0·05	0·07
Actual contamination over 3 years	Nil	0·0012	0·002	0·002
Actual contamination over 3 years allowing for mixer dilution	Nil	0·0009	0·002	0·005

Letter to the Editor

Discussion on carbides in annealed and quenched high-speed steels

WE HAVE STUDIED the origin of secondary hardening in 18–4–1 type high-speed steel by electron microscopic and electron diffraction examination of carbon extraction replicas.[1] However, we have also had occasion to examine by X-ray diffraction, electrolytic extracts prepared from the annealed and as-quenched states using a citrate cell, and can confirm the findings of Malkiewicz *et al.*[2] In the X-ray patterns M_6C lines and faint $M_{23}C_6$ lines were detected for the annealed condition, while only M_6C lines were found in the extracts from the as-quenched specimens.

Electron microscopic examination of the annealed steel showed the M_6C as a relatively coarse distribution of particles, 75% of which were between 1 and 2μ with a few much larger particles. The M_6C particles were not often extracted in the replicas but their outline remained (Fig.1). The $M_{23}C_6$ carbide was present as a finer dispersion of average size 2000–3000Å which was readily extracted in the replicas (Fig.1). Replicas from as-quenched specimens normally revealed only M_6C; however, prolonged etching led to the extraction of a fine precipitate from the grain boundaries (Fig.2) which gave electron diffraction patterns corresponding to VC. This carbide was also detected in replicas taken from fracture surfaces. We think that the presence of this carbide in the grain boundaries accounts for the virtual absence of grain growth in 18–4–1 until very high temperatures are attained (>1200°C).

It may be of interest to record that our electron microscopic and diffraction studies have indicated that the secondary hardening phenomenon which occurs on tempering is not due either to the precipitation of carbides in the retained austenite, or to the subsequent transformation of the austenite to martensite on cooling from the tempering temperature. We have found that $M_{23}C_6$ is precipitated in the martensitic matrix which has led us to suggest that the secondary hardening is a normal age hardening process similar to those occurring during the tempering of low-alloy steels containing vanadium and molybdenum.[3]

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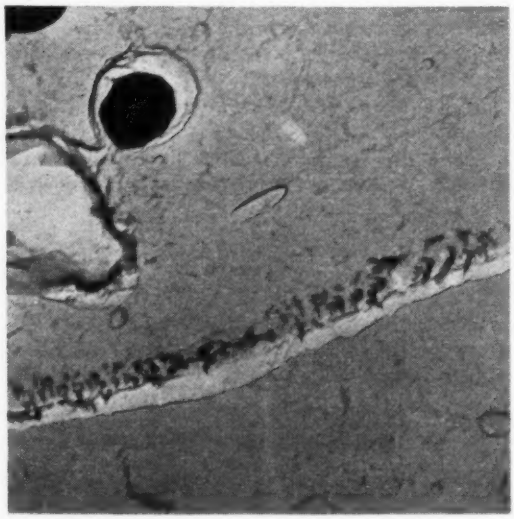
1 18–4–1 *high-speed steel, annealed. Carbon extraction replica* × 10000



2 18–4–1 *high-speed steel, as-quenched. Carbon extraction replica* × 17000

Iron and Steelworks Engineering
THE IRON AND STEEL ENGINEERS GROUP

Plate mill furnaces

The Society of Furnace Builders

SYNOPSIS

The features and operating characteristics of the different types of furnaces generally used in plate mills are described and illustrated in the present paper which has been collated from information and data supplied by several members of the Society of Furnace Builders.

Contributions from different sources, on furnaces of a particular type, are then separately presented under the heading of the furnace. The principal factors controlling the selection of furnaces for a plate mill are:

(i) quality, size, and thickness of plates to be produced

(ii) required annual rate of production

(iii) form or shape of material to be initially fed to the mill, i.e. ingot or slab

(iv) dimensions of ingots or slabs and variations likely to occur in them

(v) type and layout of mill and floor space available for furnaces

(vi) processes of heat treatment required at the finishing end of the plant.

Careful consideration of these related factors will usually clearly indicate the particular furnaces required for optimum conditions of production. 1810

FURNACES BEFORE THE MILL

Soaking pits

CONVENTIONAL FUEL-FIRED soaking pits described and illustrated in an earlier paper* are used for heating a wide range of ingots before rolling into slabs. They are sometimes used for the heating of ingots or slabs before rolling directly into plates. The earlier paper provides information on the productive capacities of the pits, and on the fuel consumption under different operating conditions.

During the past decade many electrically heated pits have been installed throughout the world, and as some of these equip plate mills their principal features and characteristics will be described.

Electric pits are arranged in cells designed to accommodate one or more ingots or slabs. The number of cells per pit depends upon production requirements. The cells have separate covers which rest in sand seals. The pits are rectangular, steel encased and well insulated. They are very economical in the use of floor space and only require simple concrete foundations.

Troughs of silicon carbide filled with high-purity coke form the heating elements of the pits and extend the full length of the chambers. They receive energy from electrodes located in the end walls and transmit radiant heat to the steel through arched openings in the brickwork. Power is usually provided through suitable transformers from a 6·6 or 11-kV supply. The power factor exceeds 0·98. Conventional instruments are employed for the automatic control of temperature and they actuate power relays.

Figure 1 illustrates an electric pit with four cells which will each accommodate one ingot of up to 10 tons in weight. This pit has two heating elements. By a simple method of atmospheric control a slight degree of scale is formed to remove surface defects from the ingots. Plates of superior finish and quality are produced.

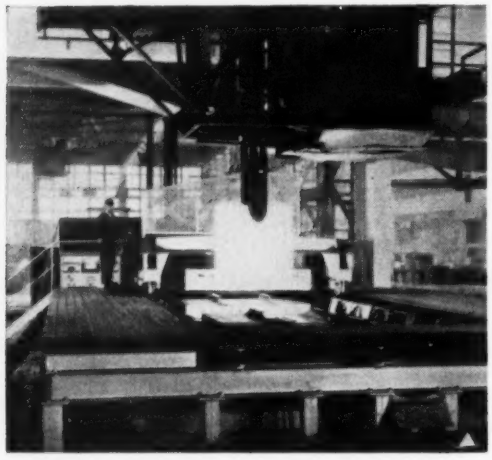
Figure 2 shows another pit which was installed for heating special steel slabs before rolling into plates. This pit will accommodate charges of up to 50 tons in weight, and has three cells which will each take two slabs. The heating elements are arranged in series and receive energy from a single-phase transformer. A particular function of this pit is to heat heavy composite slabs for rolling into clad plate. The essential requirements of temperature uniformity and clean steel surface are met without difficulty.

Electric pits consume about 330 kWh/ton when heating steel from cold to rolling temperature. This is

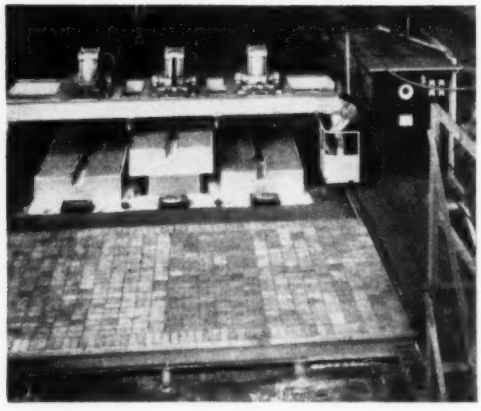
* SOCIETY OF FURNACE BUILDERS: *JISI*, 1948, **158**, 125–137.

Manuscript received 30 December 1959.

Mr H. Southern, Chairman of the Society of Furnace Builders, collated the information and data given in this paper.



1 *Electric soaking pit with four cells*



2 *Electric soaking pit with three cells*

equivalent to 11 therms/ton and corresponds to a thermal efficiency of about 75%. For soaking after very short track times consumptions of 30 kWh/ton (1 therm/ton) are easily obtained.

When required, electric pits can be equipped with fuel-burners for supplementary heating. With this provision fuel can be used to heat the charge to a predetermined temperature. The burners are then shut off and electrical energy is used to raise the steel to the desired final temperature.

Multi-zone continuous furnaces

(i)

The multi-zone fired continuous furnace offers many advantages for the heating of slabs and is widely used in plate mills of high productive capacity.

There is of course a problem in the variations of slab size and thickness and care must be exercised in scheduling flow through a furnace to achieve and maintain a charge of reasonably uniform thickness. As the heating time is related to slab thickness, variations in that dimension influence the temperature gradient within the slabs, control the temperature head that can be operated, and affect the output from the furnace. Varying slab lengths also affect 'hearth coverage' and thus directly influence production and operating efficiency.

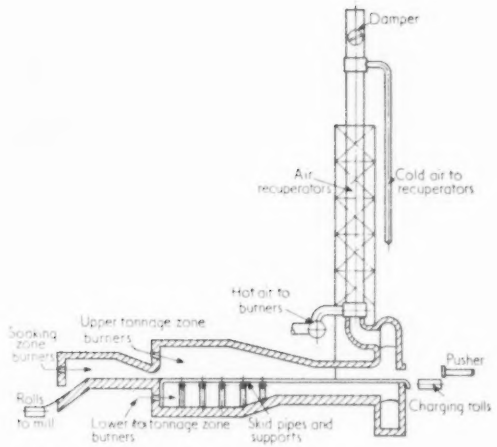
The multi-zone furnace will successfully heat slabs up to 12 in. thick and the steel is uniformly soaked at the required temperature.

The development of the multi-zone furnace is interesting. The design was patented by the Rust Furnace Company of America who advocated the simultaneous top and bottom heating of slabs with final soaking on a separate hearth before discharge. In the original furnace the lengths of the upper and lower heating zones and also of the soaking zone were carefully determined to ensure the required rates of heating. The height of the roof above the steel and the depth of the well below it were arranged to ensure correct flame development without impingement of the gases upon the steel. The roof and bottom at the charging end of the furnace were sloped towards the steel to achieve a high degree of convective heat transfer to the stock.

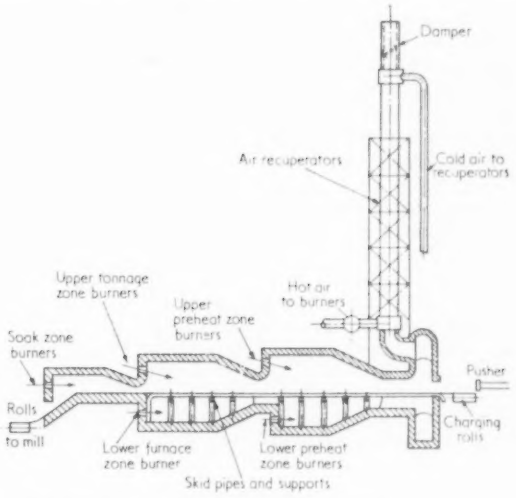
Since the original development many variations have been made by altering the position of the burners in the zones, modifying the contours of the roofs and bottom zones, and adjusting the relative positions of the upper and lower zones.

The provision of a throat at the start of the soaking zone permits operation of the zone at a slightly positive pressure and this minimizes the tendency for cold air to flow up the discharge slope and chill the front edge of the slab awaiting discharge. When an increased output is required the trend is to add further zones at the charging end. The effect upon production is then pronounced. An increase in the number of zones is also beneficial from the standpoint of furnace control. When a conventional three-zone furnace is operated beyond its rated capacity, high temperature heads are necessary, hence during mill delays or stoppages the firing rate must be quickly reduced. With additional firing zones at the charging end a lower temperature head suffices and with the facility to introduce more fuel at these zones a furnace can quickly be brought back to full production after a mill delay. The additional zones increase the flexibility of a furnace, which is advantageous when heating slabs of different thicknesses. Conventional three- and five-zone furnaces are shown in Figs.3 and 4.

During the past few years many important developments have occurred in the construction of the furnaces but the classic outline has been retained. Improved refractory materials are used in the walls, crowns, and hearths and the skid supports are insulated to minimize the loss of heat from water cooling. A recent development is hot water-cooling at high pressure, which greatly reduces heat losses, results in the production of large amounts of steam, and improves the reliability and life of the skid system. Recent furnaces have metallic recuperators for preheating the combustion air and some are erected above the furnaces and act as the chimneys. Others of the needle and tubular types are built alongside the furnaces. Automatic control of the fuel/air ratio and of the furnace temperature and pressure is always provided together with recording instruments and safeguard equipment. When alternative fuel-firing is provided, e.g. oil or coke-oven gas, the changeover is effected at the control panel.



3 *Triple-zone continuous slab reheating furnace*



4 *Five-zone continuous slab reheating furnace*

(ii)

The steady increase in mill capacity during recent years has created a demand for furnaces capable of continuously reheating steel at rates of 100 tons/h or more. The multi-zone furnace has successfully met the demand and is now widely used for heating slabs, blooms, and billets. It is occasionally used for ingots. Large slabs are easily accommodated and furnaces up to 34 ft wide are a practical proposition. Twin rows of stock are frequently charged. Furnaces with five and six firing zones have been developed for the heating of 200 tons/h of steel. Special steels present no problem because the furnace atmosphere can be effectively controlled by instruments.

For outputs of up to 20 tons/h, two-zone top firing is normally adopted. For duties between 20 and 100 tons/h three-zone firing is general practice. For furnaces 20–34 ft wide used for heating single or twin rows of stock the soaking zone is frequently split into two zones thus giving four-zone control. Temperature equality across the total width of the soaking hearth is then obtained.

Figure 5 shows the arrangement of a typical three-zone furnace and Fig.6 shows the discharge end. The design, construction, instrumentation, and operating characteristics of a furnace of this type are briefly described. Slabs are pushed through the furnace on water-cooled skid pipes which are independently supported on refractory piers up to the underfired zone, and then by cross pipes and U pipes over the lower combustion chamber. The soaking hearth has a bed of solid steel billets to support the charge and these are set in and paved with 73% alumina firebrick. Furnaces of the end-discharge type have water-cooled pipes extending down the ramp to the mill table as shown in Fig.5.

The furnace is supported by heavy rolled-steel sections and the steel casings and buckstays are of substantial construction. The suspended roof is supported by beams which span the furnace and tie the side casings. The special nose blocks at the base of the mid-upper burner wall are supported by a water-cooled beam fabricated from a broad flange section. A similar section is used for the charging-door beam, but the beam at the discharge end is of heavy steel plate construction. Both are water cooled. To minimize heat losses extensive use is made of hot face insulating material in all walls. Sillimanite is used in critical areas around the firing zones of oil-fired installations. For gas-fired units, 42% alumina brickwork suffices for the inner lining, with 37% alumina in the side walls and roof near the charging end.

Combustion gases from the overfired zones travel along the furnace over the upper surface of the stock and exhaust down wing ports at the charging end where they enter the main collecting flue. The combustion gases from the underfired zone travel under the stock, between the skid pier walls, and then enter the flue. The charge is heated on both sides from the moment of entry to the furnace, and is uniformly soaked and held at the required temperature before discharge from the soaking hearth.

The fuels normally used are gas, oil, or both combined, with or without the recuperation of waste heat. Mixtures of blast-furnace and coke-oven gas are frequently used and straight coke-oven gas is occasionally employed. With mixed gaseous fuels the air is usually preheated. With lean gas such as blast-furnace gas it is customary to preheat both the gas and the air. When it is possible to dispense with the use of recuperators waste-heat boilers are often installed.

Oil firing is usually by medium-pressure burners using steam or compressed air for the atomization of the fuel. A separate supply of air, generally preheated, is then provided for the combustion of the oil. Self-proportioning oil burners are occasionally used. They are of the low-pressure type and the air supply which is cold or only slightly preheated both atomizes the oil and burns it. Thus a high-efficiency fan capable of supplying air at a pressure sufficient to overcome the resistance of the air mains, atomize the oil, and ensure efficient mixing is all that is required for a self-proportioning low-pressure burner scheme.

Self-proportioning burners have the disadvantage of not being suitable for preheated air at temperatures greatly in excess of 250°C owing to the formation of carbon in the burner body, but they simplify instrumentation and have certain advantages in upkeep cost and maintenance.

Furnace control is fully automatic throughout, the initial control settings being maintained by three-term controllers, usually of the pneumatic type, combining proportional band, first derivative time function, and integral or reset function. The various lag factors for a given change of conditions are thus kept to a minimum and ensure the best possible furnace efficiency.

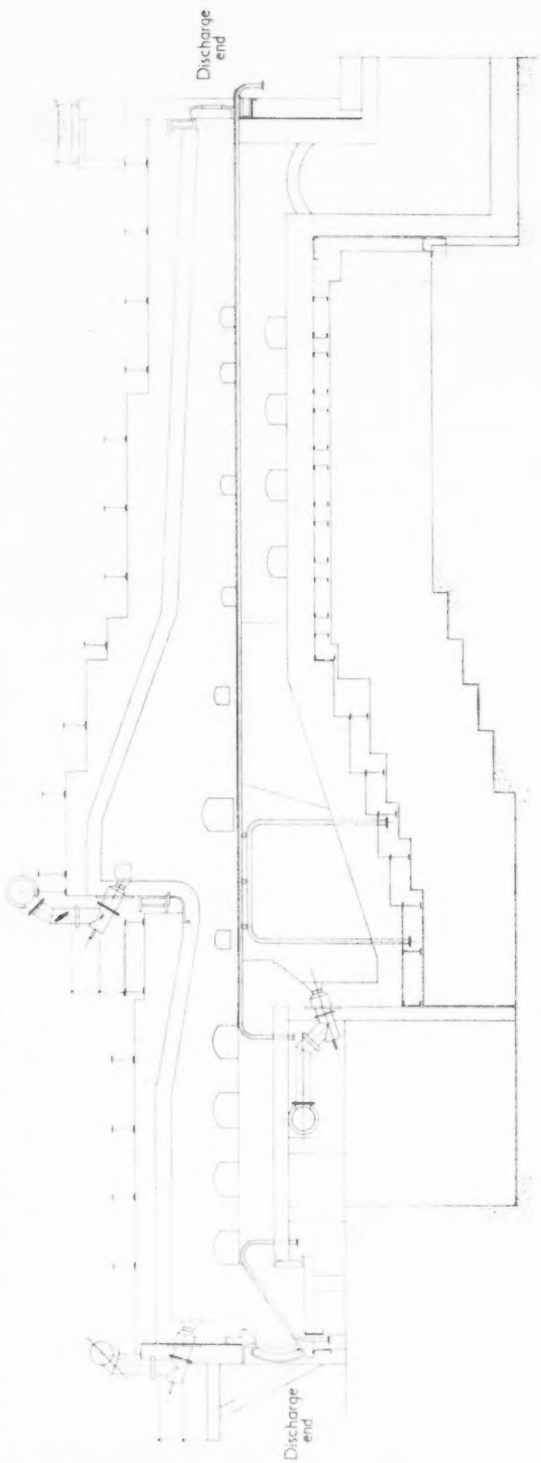
Temperature control is provided on the upper and soaking zones only, the lower zone being regulated through the upper zone by means of a proportioning or bias relay. This relay may be set to give a variety of proportions between the upper zone and lower zone temperatures, i.e. the relay may be set to give equal temperatures in the lower zone and the upper zone, in which case a controlling temperature of, say, 1250°C in the upper zone would give a similar temperature in the lower zone. An increase to 1260°C in the upper zone would result in a corresponding rise to 1260°C in the lower zone. The relay may be set, however, to give higher or lower temperatures in the lower zone, controlled with respect to the upper zone. A temperature recorder indicates the temperatures in all zones. Control is effected through cylinder-operated butterfly valves altering the fuel supply to the zones, and fuel/air ratio control for each zone is supplied, a proportioning bellows giving a change in the fuel valve position with a change in the air meter reading, the bellows being set to give a predetermined ratio of movement of the two cylinders and therefore of the valves.

Fuel and air flow metering for each zone is provided, with recording, indicating, and counting functions, together with fully automatic furnace pressure control, again three-term, to ensure immediate response of the damper to a change in furnace conditions, i.e. variation from the set point. Pressure indication and recording is supplied together with a combustion air pressure regulator and indicator.

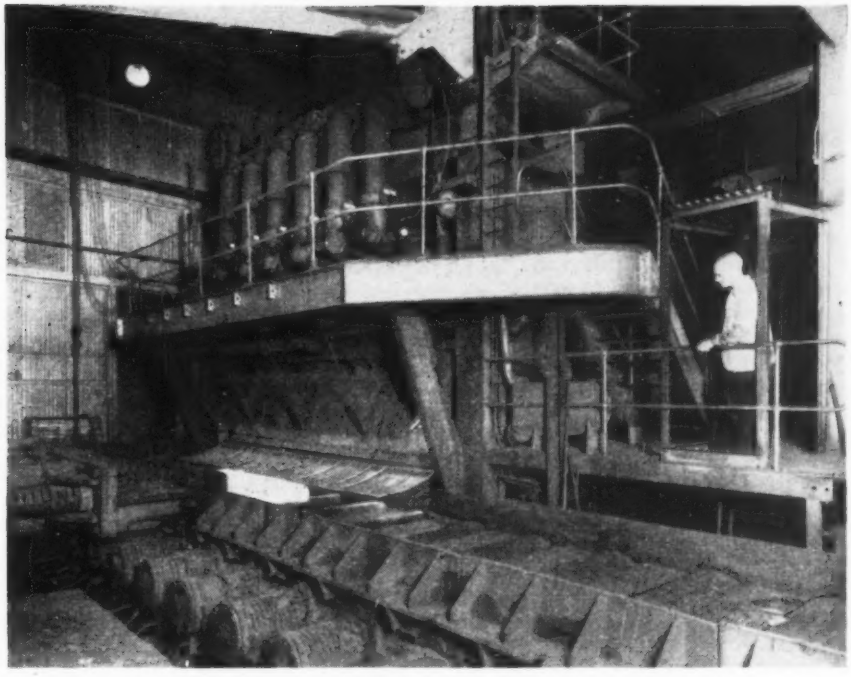
If medium-pressure oil burners are used, the atomizing medium is also ratio controlled with respect to the fuel oil, in addition to normal oil/combustion air ratio control. Self-proportioning schemes simplify the instrumentation, as oil/air ratio is completely taken care of by the burners themselves.

If recuperation is applied, the instrument panel contains a temperature recorder giving waste gas temperatures and air preheats and with alarm equipment for recuperator protection. Dilution air control is also provided, the dilution fan being started when the waste gas temperature rises to the set point.

The heat losses through the furnace brickwork are kept to a minimum by the use of good quality diatomaceous bricks and the extensive application of hot face insulating material, but the main thermal losses arise from the water-cooling system. The water-cooled skids and stand pipes in the underfired zone are the chief problem because the refractory cladding has to withstand vibration and resist high-temperature gradients. Vibration occurs when the charge is pushed through the furnace and this tends to crack and shake off the refractory rings or covers. Mullite was originally used, but the bends on the stand pipes had to be left uncovered owing to the difficulty of acquiring the special shapes required and owing to their cost. Recent experiments with different materials have, however, shown that the application, at the bends, of a special castable refractory material with stainless-steel mesh



5 *Triple-zone continuous slab reheating furnace*



6 *Discharge end of triple-zone furnace*

reinforcement has proved very satisfactory. The down legs of the U pipes are completely enclosed in brick sleeves and the skid pipes sitting on the pier walls are packed with special heat-resisting fibre. The cladding of the skids in one furnace has reduced the heat losses by 10% and cut the overall consumption of fuel from 20 to 18 therms/ton of stock heated.

The consumption of fuel depends upon the degree of waste heat recovery and upon the effectiveness of the skid cladding, but in all cases ranges between 18 and 22 therms/ton of stock heated. A consumption of 11 000 ft^3/ton is typical of a furnace heating 45 tons of steel per hour on mixed blast-furnace and coke-oven gas with a calorific value of 170 Btu/ft^3. This represents 18·6 therms/ton or an overall efficiency of 47%. The air is preheated to 500°C.

(iii)

Continuous multi-zone furnaces of the type shown in Fig.7 are used for slab heating on the Continent and are now available in the UK. The tonnage zone is top and bottom fired and the soaking zone is reverse fired with the gases directed towards the discharge door. The pressure resulting from reverse firing minimizes the ingress of cold air and is effective in reducing scale losses.

The particular furnace illustrated is fired with blast-furnace gas of 110 Btu/ft^3 and is equipped with metallic recuperators which preheat the combustion air to 700°C and the gas to about 400°C. Exhaust gases enter the recuperators at an average temperature of 900°C.

The temperature conditions within the three zones of the furnace are automatically controlled from six points located within the 'half-width' of each zone and this ensures complete control of the temperature along the axes of the slabs. Each of the six temperature controllers has its associated fuel/air ratio controller which is operated from the air manifold. Furnace pressure control is provided and when an induced draught fan is used vane control is usually adopted. A scoop or fluid coupling is installed between the motor and the fan to conserve power when the furnace is operating at reduced output.

When the skids of the furnace are of the normal water-cooled type all but the sliding surfaces are insulated with specially formed blocks which considerably reduce the heat losses. With carefully insulated skids the saving in fuel approaches 30% in furnaces of high productive capacity. Even greater economy is achieved with 'evaporative cooling' of the skids. From 85 to 95 tons of saturated steam have been produced in 24 h from 'evaporative cooling' of the skids in a furnace of the type shown in Fig.7. This represents a considerable recovery of heat and the saving is reflected to a marked degree in the overall thermal efficiency of the furnace.

Another Continental furnace, of the multi-zone type with a series of separately fired chambers, is also available in the UK. This furnace is suitable for the heating of slabs up to 15 ft long and 12 in. thick and provides top and bottom heating of the stock throughout the full length of travel. The arches of the chambers are parabolic in shape and completely encased in steel plates. Because of their shape the heat losses are minimized and the sensitivity of pressure control is greatly improved.

The furnace has refractory skids and the thermal losses of water-cooled skids are completely eliminated. As each zone of the furnace is separately fired the rate of heat transmission to the stock can be effectively controlled to achieve maximum throughput with a minimum loss from scaling and decarburization.

Metallic recuperators are used for the preheating of

the combustion air and the waste gases are evacuated by an induced-draught fan. Full automatic control is provided and overall thermal efficiencies up to 70% are claimed. The furnace is ideal for oil-firing.

Reversing regenerative continuous bogie furnaces

(i)

For several years a number of furnaces of the type and arrangement shown in Figs.8 and 9 have been in regular service at a large Midland steelworks.

These furnaces each accommodate 11 bogies and each bogie normally carries an average load of 15 tons of slabs varying in thickness from 7 to 11½ in., and from 60 to 99 in. long. The bogies are pushed through the furnaces by electrically operated mechanisms which are interlocked with the lifting gears of the charging and discharging doors.

The fuel used at present is mixed blast-furnace and coke-oven gas with an average calorific value of 160 Btu/ft³ and a pressure of about 6 in. wg. A richer gas of 200 Btu/ft³ has been used, and during the acceptance test and following figures were obtained:

Mean temperature of slabs as drawn, °C	1310
Rate of drawing slabs, tons/h	12·46
Average bogie load, tons	15·35
Gas used per ton of slabs, ft³	10060
Calorific value of gas used, Btu/ft³	203
Equivalent gas volume at 200 Btu/ft³ per ton of slabs heated, ft³	10200

The furnaces are divided into two zones for convenience of operation and control. The zones are separated by a brick arch, which closes the gap between the slabs and the roof and permits effective control of the pressure conditions within each zone. Mutual interference is reduced to a minimum. The gas and air for combustion enter the furnaces through ports along both sides. The ports are level with the tops of the bogies, and direct the flames vertically. As the furnaces are of the reversing type, combustion of the gas alternates from one side to the other. Induced draught is employed for the withdrawal of the waste gases.

The air regenerators are of the multi-pass, horizontal type and extend the full length of each furnace, but are separated by walls to suit the lengths of the zones. Two automatic reversing units are provided (one per zone) and each operates an air/waste-gas reversing chest and two water-sealed gas valves. The valves are electrically operated and automatic reversal is controlled by panels. The reversal periods may be varied from 10 to 30 min. Push-button hand control is also provided. Separate and independent automatic control of temperature, air flow, and furnace pressure is provided for each zone.

The cold slabs enter the preheating zone and are gradually heated to a temperature of about 1200°C before reaching the final heating zone where they are fully soaked and held at a specified temperature to suit the mill requirements. The design of the furnaces is such that large variations in stock size and thickness do not seriously affect performance. The particular air-regenerative system is ideal for the conditions of application and ensures good temperature distribution with high air preheats under the varying demands of the mill. The figures given below were obtained during a 50-h test, and are typical of normal performance:

Average dimension of slabs, in.	40·5 × 8·3 × 75
Limits of variation, in.	38–42 × 7–11½ × 60–99
Average weight of slabs, lb	7160
Average number of slabs per bogie	4·8
Average weight per bogie, tons	15·35
Average rate of drawings	1 bogie per 1·233 h
Average temperature charged, °C	50
Average temperature leaving preheat zone, °C	1175
Average temperature drawn, °C	1310

The furnaces described have been in operation for about 15 years but two new furnaces have recently been commissioned in the same bay. These were installed to heat cold slabs to a rolling temperature of 1300°C at an average rate of 18 tons/h. Slab sizes are 41 – 44 in. wide extending up to 52 in. wide and present production is largely based on 52-in. slabs with thicknesses ranging from 7 to 17 in. and lengths ranging from 60 to 99 in. The furnaces are identical in length with those originally installed but the bogies are wider. Each bogie was designed to carry a maximum load of 30 tons but the average load is 20 tons. For continuous operating conditions, a heat consumption of 18 therms/ton was envisaged from the use of mixed blast-furnace and coke-oven gas with a calorific value of 160 Btu/ft³. In practice the new furnaces have heated 18 tons/h at 18 therms/ton solely on blast-furnace gas with a calorific value of 100 Btu/ft³.

A number of improvements and modifications have been incorporated in the new installations, the more important of which are briefly described. To achieve a greater output without increase of furnace length the zone lengths have been modified. Whereas the existing furnaces have heating and soaking zones of equal length, the new furnaces have proportionately longer heating zones than soaking zones. The temperature head in the heating zones is also appreciably greater than in the original furnaces.

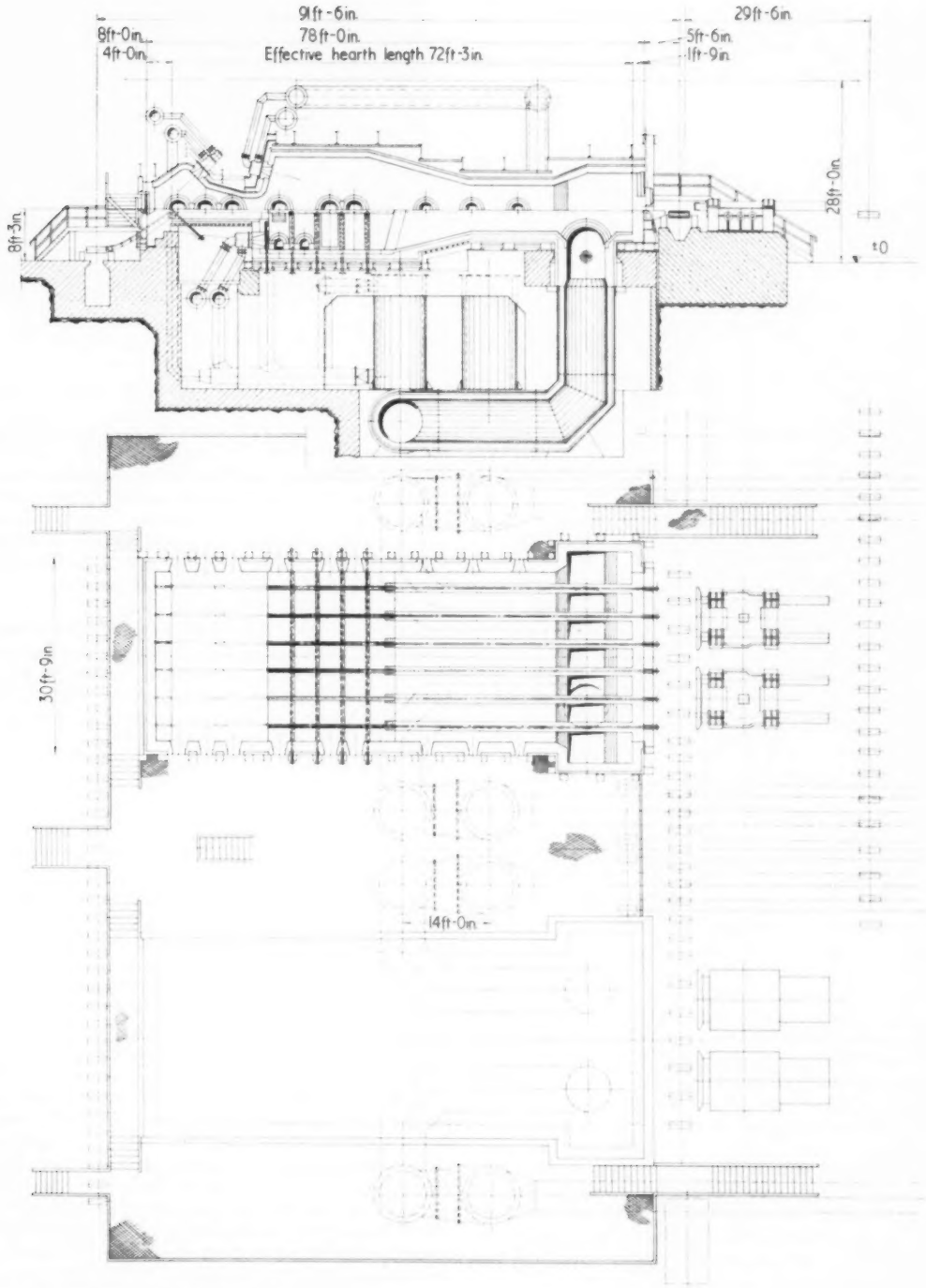
To limit air infiltration to the minimum, the regenerators on both sides of each furnace have been totally encased in steel plates. In earlier installations excessive infiltration reduced the temperature of the waste gases, adversely affected the degree of air preheat, and reacted upon the furnace efficiency.

Additional heat recovery equipment has been installed to preheat the gas supply. Over each zone of the furnace a separate recuperator of the finned metallic type has been introduced. These recuperators are single pass on the waste-gas side and five pass on the fuel side. With optimum conditions of flow they preheat the gas to 400°C.

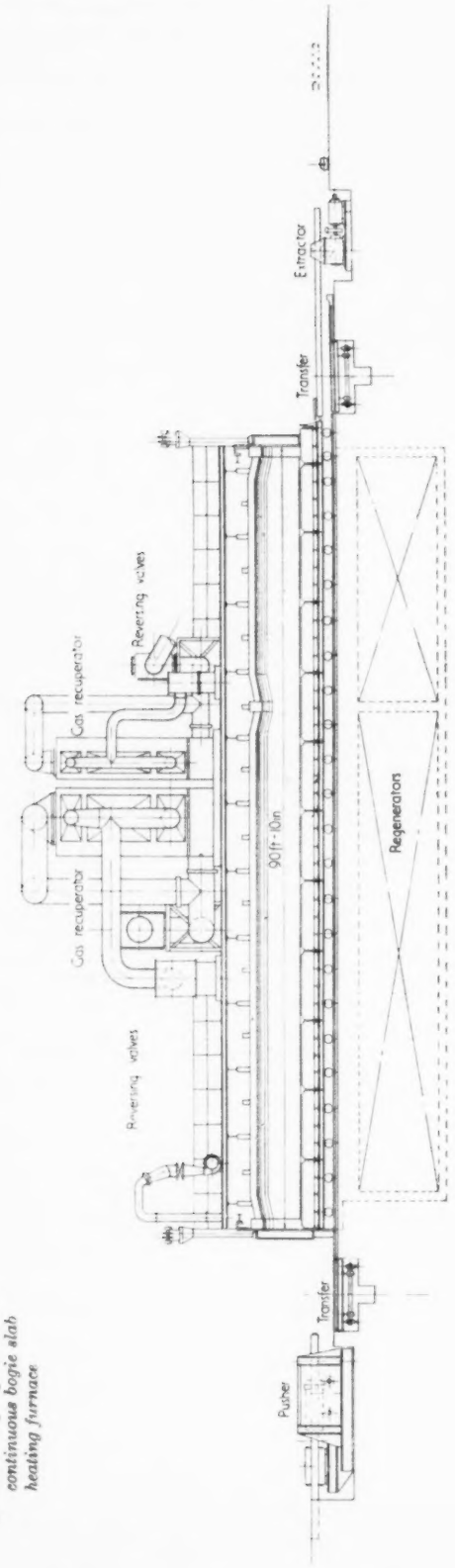
The large refractory concrete plinth supporting the furnace rails and bogies of the earlier furnaces and separating the regenerators on either side has been replaced by a substructure of steelwork. This has permitted the complete tanking or encasement of the air regenerators in the new furnaces.

Lockheed hydraulic cylinders for the reversal of the gas and air exhaust valves have been adopted. The type of automatic reversal panel employed on the original furnaces has been retained together with push-button hand control.

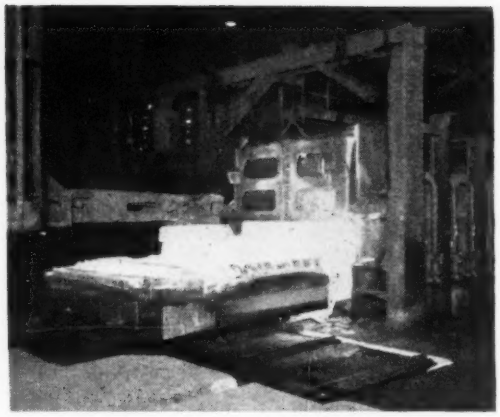
Firing of the preheating zones has been extended to the charging doors, thus utilizing the full lengths of the furnaces. Only ten of the eleven bogies in the original furnaces were actually within the effective firing zones, the eleventh remaining in an unfired



7 *Triple-zone continuous slab reheating furnace*



8 *Reversing regenerative continuous bogie slab heating furnace*



9 *Discharge end of reversing regenerative bogie furnace*

'tunnel' at the charging end until pushed into the furnace proper.

Pad-type lubrication has been provided for the bogie wheel bearings.

For mills dealing with slabs of different sizes and thicknesses, the bogie-type reversing furnace provides a satisfactory method of reheating, with good control and equality of temperature and the easy attainment of high temperatures from lean gases. It is a self-contained unit with completely mechanized bogie transfer cars and haulage mechanisms.

When mill production necessitates the installation of several furnaces of the reversing-bogie type, the initial capital expenditure is high. It is, however, offset over a reasonable period by the economical costs of operation and the reliability associated with this type of installation.

Rotary hearth furnaces

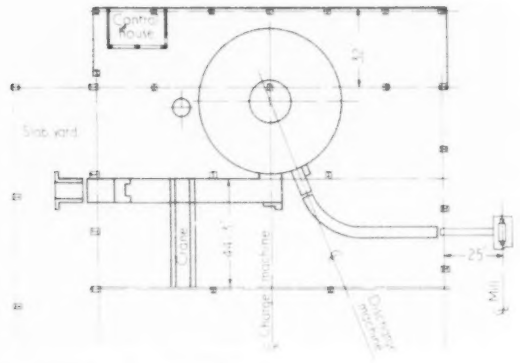
(i)

The use of rotary hearth furnaces for slab heating is a recent innovation in the UK and is the outcome of developments in the USA.

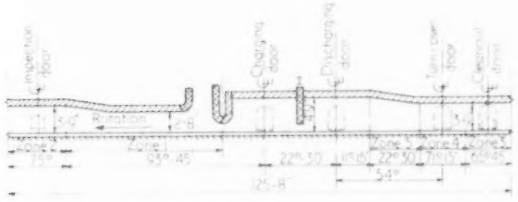
Rotary hearth furnaces are now widely employed both in the UK and abroad, for heating ingots, blooms, and billets in the manufacture of disc wheels, tyres, rings, tubes, etc. They are flexible in operation and ensure uniformity of heating with economy in the use of fuel.

During 1952 and 1953 one US firm reviewed its production of steel plates from the open-hearth shop to the inspection and shipping bay and inaugurated a scheme of modernization which was completed in 1954. A new slab mill was installed in 1953 to feed an existing mill in which plates from $\frac{1}{8}$ to 1 in. thick up to 72 in. wide and up to 480 in. long had to be produced. With these wide variations in plate dimensions it was essential to use slabs ranging in weight from 500 to 5000 lb and in thickness from 3 to 8 in., so a flexible method of heating had to be adopted. Furthermore the furnace had to be suitable for installation on an existing site of limited area.

After considerable study of the many problems involved it was decided to install a rotary hearth furnace and Fig.10 shows the layout of the plant which consists of a stacking bed, de-piling crane, five-strand



10 *Layout of rotary furnace installation*



Zone	No. of burners
1	*0*
2	*12*
3	*12*
4	*12*
5	*5*

11 *Unwound view of rotary furnace*

conveyor, charger, rotary hearth furnace, discharger, and curved and straight table to the mill.

Slabs are deposited in piles on a stacking bed in the slab yard, by a tong-type crane which has a fixed bumper for end-of-pile positioning. A de-piling crane with bridge and hoist motions only and a double magnet then deposits the slabs on a 10 ft/min five-strand conveyor. Because of the bumper already mentioned, the furnace end of the slab is correctly located in relation to the fixed jaw of the furnace charger. At the furnace end of the conveyor there exists a power-operated movable bumper with position indicator and conveyor limit stop switch. The movable bumper allows the operator to arrest slabs of varying width in a central position under the jaws of the charging machine.

As already indicated the furnace end of the charging machine peel has one fixed jaw, and clamping is done by a hydraulically operated moving jaw on the end of the carriage. The slab is raised from the conveyor, and then charged into the furnace in single row or double row assembly dependent on the slab length. The settings are controlled by the operator and can be very quickly changed as required. The discharge unit is a duplicate of the charging machine.

The furnace has an outside hearth diameter of 55 ft and a hearth width of 15 ft, giving an area of 1885 ft². The hearth indexes to give any desired setting from 33 to 84 rows. Charging, hearth movement, and discharging can be manually or automatically controlled as desired. The maximum charge and discharge rate is 75 pieces per hour.

The furnace proper is arranged in five zones with burners applied to zones nos.2–5 inclusive. The combustion gases travel counterflow to the hearth rotation, and are discharged to the stack from a point near the charging door in zone 1. Burners are combination oil or gas for heavy fuel oil and coke-oven gas. Maximum fuel input is about 130×10^6 Btu/h. The charging door is on a radial line at right-angles to the cold slab conveyor with the discharge door spaced $22\frac{1}{2}°$ away.

The furnace is a conventional rotary hearth furnace with zone no.1 being a preheat zone taking advantage of the heat in the waste gases before they go to the stack and also of the thermal storage in the hot hearth. Zone 5 is a very short soaking zone, perhaps more effective in counteracting the cooling effect of the discharge door opening than in actual soaking or heating.

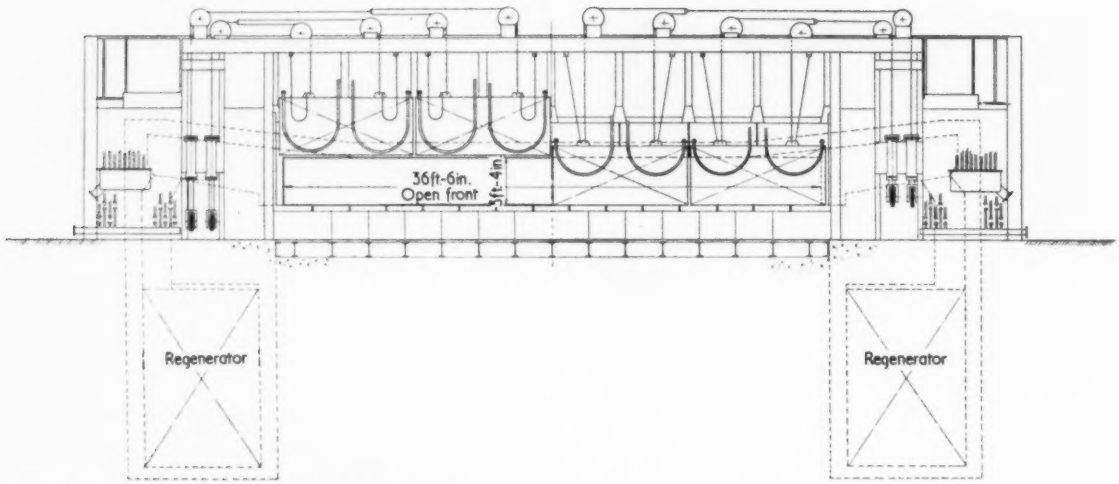
The furnace is fired with 41 combination coke-oven gas and steam atomized heavy fuel oil burners. Zone control of temperature is motivated by closed-tube radiation units located in the side walls. Separate combustion air fans are used on each zone and the air/fuel ratio is controlled by hydraulically operated butterfly valves. Fuel and air flow to each zone are metered, and a master meter is installed to indicate the total fuel input. The furnace pressure impulse is obtained through the roof near the charging door, and control is effected by means of a vertical stem water-cooled butterfly valve with hydraulic operator located in the overhead waste-gas flue. Power for operation of the damper and the fuel/air ratio controllers is supplied by a dual pump arrangement. Temperature-control instruments regulate standard electrically driven valves in the fuel lines of each zone.

The rotating hearth consists of a lower framework of welded joists and channels, and carries the wheel bearings and rack castings. Upon the lower frame an additional welded structure is loosely mounted, and because it can float in any direction it combats any tendency of the hearth supporting steelwork to become distorted during expansion or subsequent contraction.

The upper framework has an angle curb casting mounted around the edges to retain the hearth brickwork. On the inner side of the lower framework a rolled steel channel is fitted and equipped with a rubbing strip which acts as a thrust ring to keep the hearth in alignment with the aid of spring mounted rollers. Power to rotate the hearth is supplied through suitable motors coupled to reduction gears. The outer side wall of the furnace is of normal construction but the inside wall is anchored to the steel shell to counter any tendency of the wall to increase in the circumferential direction during heating. The roof is usually of the flat suspended type, although in certain cases a normal arch is used.

A fabricated steel water-filled trough is mounted on the base steelwork which supports the rail track under the inner and outer edges of the hearth steelwork. Two dipper seals, one attached to the hearth top steelwork and the other to the wall supporting shelf steelwork, fit into the trough and form an effective seal.

The counterflow of gases against rotation has been mentioned and is helped by curtain walls between the charging and discharging doors. Figure 11 shows an unwound view of the furnace, with roof contour, charge and discharge doors, baffles, and stack take off.



12 *Reversing regenerative 'open front' slab heating furnace*

It emphasizes the length of hearth obtainable from a rotary furnace and indicates the suitability of this type of furnace for installation on limited or confined sites. In recent years the advantages of this type of furnace for heating material of substantial cross-sectional dimensions have been recognized.

The arrangement of the US furnace and conveyors shown in Fig.10 ensures truly continuous operation from the slab yard to the mill, which is achieved by the efficient use of limited floor space. Many problems are encountered in the continuous heating of slabs ranging in thickness from 3 in. to, say, 10½ in., and a difficulty arises when the thickness of the slab, at charging, is changed several times a day. The slab thickness determines the heating time, hence when the simultaneous heating of slabs of different thickness is necessary the heating time for the thickest slab controls production. Skill in scheduling is therefore vital to output and furnace efficiency.

From US experience, rotary furnaces can generally be accommodated within existing mill layouts, and it is interesting to note that about 60% of the rotary hearth furnaces employed in the US equip mills which have been reorganized or modernized from the original layouts.

'Open front' furnaces

(i)

These furnaces, as the name implies, have no intermediate jambs to obstruct the charging opening. The entire front of each furnace is spanned by a massive water-cooled beam, which acts as an arch plate for the hydraulically operated water-cooled doors, and also supports the suspended roof. Every part of the hearth is accessible for use and stock of various sizes can easily be accommodated.

The 'open front' furnace shown in Figs.12 and 13 is of the air regenerative/gas recuperative type, and the gas and air exhaust reversing valves together with the automatic reversal panel are similar to those applied to the bogie-type furnace illustrated in Figs.8 and 9. Metallic recuperators are used, either of the tubular type for gas preheat temperatures up to 250°C or of the extended needle type for temperatures up to 350°C. In either case the recuperator is housed in a refractory-lined mild-steel casing with removable cramped arches and lifting beam. Heat recovery in the regenerators is achieved by the use of horizontal multi-pass flues or passages.

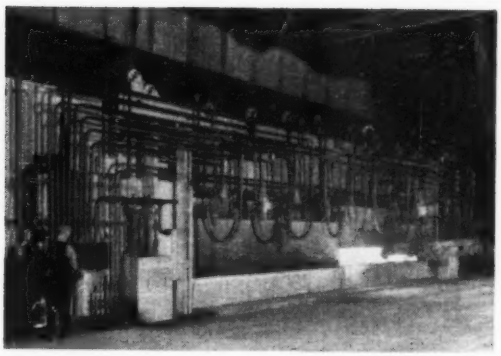
The latest furnaces use clean blast-furnace gas with a calorific value of 100 Btu/ft³. Mixed blast-furnace and coke-oven gas may also be used. The fuel is introduced above the ports leading upwards from the regenerators, and the waste gases are withdrawn by induced draught through the ports at the opposite end of the chamber. The flow is periodically reversed.

These furnaces are usually charged with hot stock at a temperature of about 900°C, and the slabs are then quickly heated to the desired rolling temperature. Recent figures in relation to a furnace fired with blast-furnace gas of 100 Btu/ft³ show an output of 13 tons/h on an average consumption of 10000 ft³ of gas per ton. When cold stock is charged the output ranges from 6 to 8 tons/h.

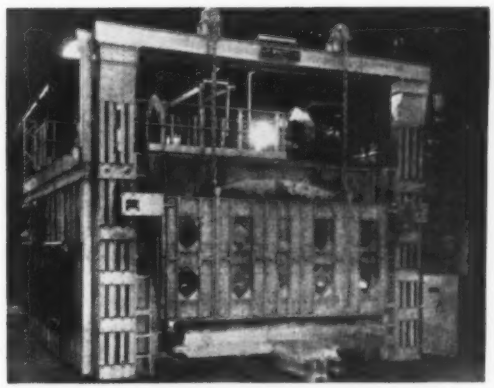
Very high temperatures are maintained in 'open front' furnaces, and it is essential to use high-grade materials in their construction. In the furnace shown in Figs.12 and 13 a hard wearing 73% alumina firebrick is used for the hearth with straight magnesite underneath as a slag resisting medium. The zones at the port ends are, however, paved with magnesite and 50% alumina firebrick is used in the sections of sloping suspended roof immediately above them. The port end walls and benches are constructed in chrome brick down to the regenerators. The remainder of the furnace is built with 42% and 37% alumina firebrick, but 42% alumina is used in the central section of the suspended roof.

Slag notches are provided in the furnace hearth and the slag is tapped into ladles through the rear wall of the furnace. The walls of the furnace and those of the regenerator chambers and recuperator setting are insulated with diatomaceous brick to an average thickness of 4½ in. The mild-steel water-cooled doors are lined with hot face insulating brickwork.

Furnace instruments are limited to a furnace pressure recorder, a gas flow meter, an air flow meter, and



13 *Reversing regenerative 'open front' furnace*



14 *Reversing regenerative furnace for batch heating of 10–20 ton ingots*

motorized valve regulators for the gas and air control valves. Automatic temperature control may be applied but is not strictly essential because the reversing regenerative principle ensures good thermal distribution for fluctuating loads within reasonable limits. Automatic furnace pressure control may be adopted but manual control is adequate for all normal purposes. Push-button operation of the gas and air valve regulators is provided from the instrument panel. Cold, clean gas-fired units are always equipped with gas and air flow meters. For the protection of the recuperator a temperature recorder is fitted to show gas preheat and waste-gas temperature.

Batch-type bogie furnaces

(i)

Figure 14 shows a bogie furnace of the reversing regenerative type which is employed in a heavy plate mill for the batch heating of 10–20 ton ingots. The furnace is fired with clean cold producer gas of 178–167 Btu/ft^3 and regularly heats ingots of all qualities up to temperatures between 1170° and 1250°C.

The bogie has a width of 15 ft and an effective length of 27 ft 7 in. The heating chamber is 21 ft 4½ in. wide between the side walls and 7 ft 6 in. high above the top of the bogie. The furnace is equipped with primary and secondary regenerators for the preheating of the air for combustion and these are located below ground level. Gas and air reversing valves and also the chimney are situated at the rear of the furnace.

The bogie is charged and withdrawn at a speed of 40 ft/min by an electrically operated haulage mechanism of 30 hp which engages with a pin-rack attached to the underside of the bogie structure. The special steel pins of the rack are 3 in. dia. at centres of 6 in. and they mesh with the final spur wheel of the drive which has teeth of special characteristics to ensure correct engagement and smooth running. The underside of the bogie is fitted with four 85 lb/yard FB rails which are arranged in pairs on each side of the pin rack. These travel on 12½ in. dia. centrally flanged cast-steel bobbins which are assembled, at centres of 2 ft 6 in., in floating carriages or frames of channel construction. The bobbins travel in turn upon a composite rail track with joist sleepers. The travel of the bogie is controlled by limit switches and an 'inching' device is provided.

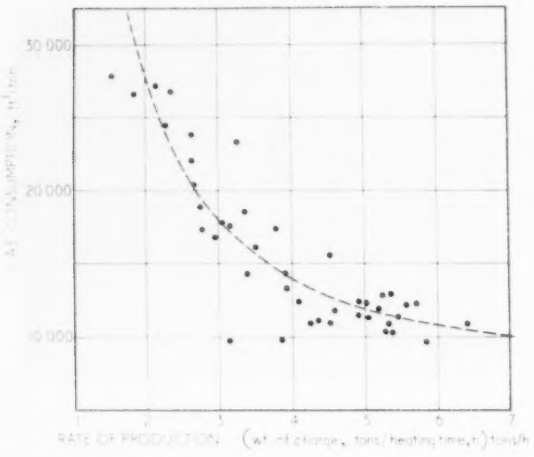
The charging door of the furnace consists of a frame of steel castings with continuous forged steel lifting bars. The frame is lined with high-temperature insulating bricks and the complete door is electrically operated at a speed of 10 ft/min from a 10 hp motor. Gear-driven limit switches are provided to arrest door travel at each end of the stroke.

The furnace is steel encased and substantially braced with buckstays and binders of heavy section. All the refractory materials used in its construction are of carefully selected quality suitable for the particular conditions of application. The gas supply to the furnace is connected to a breeches pipe which feeds two water-sealed bell-type reversing valves. It then flows from one or other of the valves through a manifold with branch connections to the burners or feeders on one side of the furnace. Combustion air is supplied at a pressure of 3½ in. wg from a fan which is connected to a butterfly air reversing valve. It then flows to the primary and secondary regenerators where it is effectively preheated. The furnace operates under mechanical draught from a venturi-stack with fan and injector.

The 12 burners or feeders on each side of the furnace have nickel–chrome cast-iron bodies with machined orifices. They each have a maximum capacity of 8850 ft^3 of gas per hour when the gas is supplied at a pressure of 6 in. wg. The limit of gas supply to the furnace is therefore 106200 ft^3/h because 12 burners only are in use at one time. The maximum supply is equivalent to a gross thermal input of about 45000 Btu/ft^2 of hearth per hour; a provision which is adequate for any operating requirement.

The furnace is automatically controlled and reversed to ensure optimum conditions of operation. The gas and air reversing valves are interconnected and actuated, at preset intervals of time, by a motorized unit of 2 hp. The period of reversal depends upon requirements and is normally 20 min. The presetting device provides any desired period between 10 and 90 min.

Furnace instruments are housed in a pressurized cabin and include fully floating temperature control equipment with a six-point recorder, a gas flow meter, and equipment for the control of the air/gas ratio, gas pressure, and furnace pressure. Air/gas ratio and gas pressure are remotely controlled.



15 *Relationship between fuel consumption and production in reversing regenerative bogie furnace*

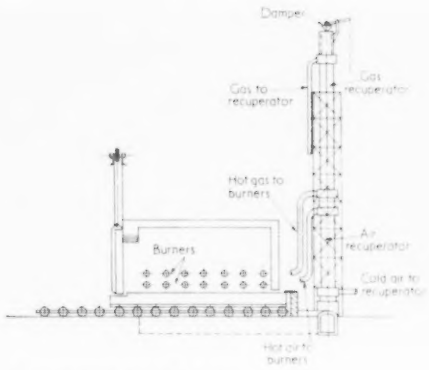
The consumption of fuel per ton of ingots heated is greatly influenced by the weight of the charge and the duration of the heating cycle, two factors which depend upon the requirements and circumstances of production. The records of 43 consecutive 'heats' over a period of 83 days have been examined and the actual figures of fuel consumption per ton of ingots heated are plotted in Fig.15 in relation to the hourly rate of production. The superimposed curve shows the trend or character of the relationship and clearly illustrates the pronounced effect of productivity upon furnace efficiency.

Throughout the period of 83 days the furnace was shut-down each weekend and was only in use on three to five consecutive days per week owing to a recession in trade. Even so, it heated 4243 tons of ingots at an average rate of 3·8 tons/h on a consumption of 14600 ft^3 of gas per ton of ingots. This is equivalent to 26 therms/ton. Despite these adverse conditions the overall thermal efficiency of the furnace averaged 30·8% throughout the particular period. The furnace is capable of heating cold steel to 1250°C on a consumption of 20 therms/ton when the rate of production is maintained at not less than 5½ tons/h. This corresponds to an overall efficiency of 40%.

(ii)

For slabs which are too thick for uniform heating in normal continuous furnaces of the pusher type, for extra large and thick slabs for special plates and also for ingots to be directly rolled into plates, the bogie furnace fulfils a useful purpose. Furnaces of this type are suitable for different fuels and are equipped with regenerators and recuperators. Figure 16 shows a furnace with a bogie 22 ft 6 in. long by 15 ft wide which is suitable for the simultaneous heating of a number of 20-ton plate ingots. The furnace is fired with clean producer gas and to obtain the necessary temperature the gas and air are both preheated in chimney recuperators at the rear of the furnace. Such recuperators eliminate the need for deep foundations; a particular advantage where water is a problem. The foundations are simple and inexpensive.

The burners are of special design for the use of preheated gas and air, and are arranged at two levels on each side of the furnace. The lower burners promote circulation of the gases under the ingots on the bogie. The outlet ports are at hearth level and connect to flues along the sides of the furnace which feed the recuperators. The gas recuperator is mounted above the air recuperator and a short extension above the gas recuperator provides a chimney from which adequate draught is obtained. Gas and air are preheated to a high degree and conveyed in insulated mains to the furnace burners. No difficulty is experienced in obtaining furnace temperatures of 1250°C and over.



16 *Bogie furnace for slab heating*

The bogie is of the conventional type with sand seals on both sides and it travels on heavy bobbins or rollers. Electric haulage is provided by suitable chains. The furnace door at the front is of robust construction and is operated by an electrical winch. The bogie projects through the rear of the furnace and is sealed with sand between the bogie and the rear wall.

Full automatic control is provided for temperature, fuel/air ratio, and furnace pressure, with adequate safeguards against failure in the supply or flow of fuel or air. Automatic control equipment ensures minimum scaling.

FURNACES AFTER THE MILL

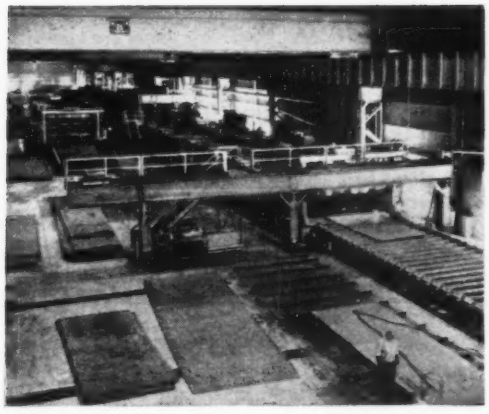
Continuous line process for the heat treatment of steel plates

(i)

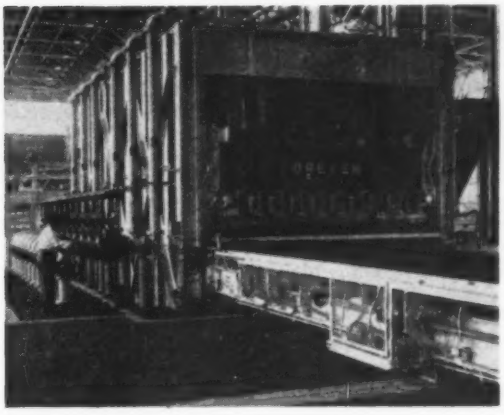
The first plant of major productive capacity for the continuous line treatment of steel plates was put into operation at the Lukens Steel Company of America in July 1955 and led to the installation in 1957 of additional and larger facilities at the Homestead District Works where further expansion is taking place. Two similar plants are now operating in Japan and both are likely to be extended later this year. Identical plants of proved design and construction are now available in the UK.

General layout

A complete installation is illustrated in Fig.17 and includes a charging transfer car, a 145-ft hardening furnace, a pressure quench, a quench transfer car, a 200-ft tempering furnace, two conveyor tables, and at the end of the line two transfer cars. Although the plant was primarily designed for the production of both armour plate and a commercial heat-treated



17 *Charging end of a 'continuous line' plant showing a steel plate entering the hardening furnace*



18 *Pressure quench and transfer car*

plate, the pressure quench is provided with a roller conveyor which, when required, will carry the plates straight through the quenching machine for normalizing.

The complete line is of the roller type with driven rolls for the automatic handling of the work. All the drives are reversible and arranged for operation from a central control pulpit. For selective operation of the drives electric clutches are provided. Within the temperature limits of the furnaces, the line is capable of handling plates up to 172 in. wide, $\frac{3}{16}$–3 in. thick, and 480 in. long for quenching, or 575 in. long for normalizing and air-cooling. When dealing with armour or other similar heat-treated plates with a width of 102 in., a thickness of 1 in. and a length of 380 in. the rated capacity of the line is $10\frac{1}{2}$ tons/h. This figure is based on 92% effective hearth loading with an end-wise clearance of 3 ft between the plates. The hardening cycle is $2\frac{1}{2}$ h and the tempering cycle $3\frac{1}{2}$ h. The maximum capacity of the line is 22 tons/h of hardened and tempered plate. This production is based on plates of the maximum width, thickness, and length with 92% end-to-end loading of the hearth.

Hardening furnace

The hardening furnace is designed for a maximum operating temperature of 900°C and a minimum temperature of 400°C. It has a wall-to-wall width of 190 in. and a length of 145 ft. The furnace is continuously fed at its particular operating speed by swing gears which engage the car roll drive with the furnace drive.

The main furnace drive is an electronic ac–dc unit of 4:1 variation with a mechanical speed changer which will give an overall reduction of 8:1, or a roll speed of 0·6–4·8 ft/min. This provides a furnace heating time which can be controlled between 30 min and 4 h. The rolls are sectionally arranged and driven from a line shaft which runs parallel with the furnace. The take-off at each section incorporates a reducer. The roller chain sprockets are fitted with shear keys and automatic chain take-ups are provided to combat slackness when the roll drive is reversed.

At the discharge end of the furnace a run-out section is provided for plates of both 30 and 45 ft length. From clutches selected in the pulpit the required operating conditions are obtained to discharge single plates to the quench at a speed of 175 ft/min, or onwards for air cooling when required. Single chains suspended from the furnace roof indicate to the operator by light and audible signal when the work has advanced to the runout section and is ready for discharge. The furnace rolls are produced from centrifugally cast chrome–nickel alloy and are 14 in. dia.

The refractory lining of the furnace consists of insulating firebrick and block with one course of hard brick on the floor to withstand the mechanical abuse of roll installation and removal. The furnace has a flat suspended roof of rammed plastic material. The roof is 9 in. thick with firebrick anchors throughout at centres of 12 in. A $2\frac{1}{2}$ in. course of lightweight cast block insulation is installed on top to seal the entire construction. The air setting plastic used in the roof gives initial strength during the period between ramming and firing when a positive ceramic bond is obtained. The steel frame doors have cast-iron sections on the surfaces exposed to heat and are lined with a lightweight castable material.

The total maximum thermal input to the furnace at the limit of burner capacity is 56×10^6 Btu/h or about 35000 Btu/h/ft² of hearth in the heating section, and about 15000 Btu/h/ft² in the holding or soaking end. The average heat input at the maximum rating of 22 tons/h is about 25×10^6 Btu/h.

Pressure quench

The pressure quench shown in Fig.18 has an effective width of 180 in., a length of 45 ft, and clear height of 18 in. It is oil hydraulically operated to exert a maximum pressure of 2500 tons on a plate 172 in. wide by 40 ft long.

The press is not a forming press and its sole purpose is to keep the plate flat during the quenching cycle. It is structurally designed for minimum deflection and will exert a maximum pressure of 4·5 tons/ft² on the material being quenched. Work is conveyed to the press, at the speed of the furnace runout, on tubular steel rolls which are operated by a continuous chain-drive connected through clutches to the furnace run-out drive. The rolls are mounted on a structural table which is assembled and guided within the press structure and raised or lowered by hydraulic cylinders.

There is a stationary platen between and below the rolls with a movable platen above which is guided on the press columns and actuated from above by 26 hydraulic cylinders. Twelve of these are for movement but all 26 exert pressure to maintain the plate flat during quenching.

A self contained oil hydraulic unit complete with solenoid control valves, boosters, pumps, and reservoir is used to supply oil, at a pressure of 2500 lb/in^2. A prefill system is used to fill the 26 cylinders rapidly on closure of the press and this ensures full volume in the cylinders before high pressure is admitted from the boosters. By means of electrically selected circuits, high pressure can be applied to one, two, or three sections of the press, dependent on plate length, which prevents damage to the sections of the structure which do not contain plate. The oil pressure at the inlets of the hydraulic boosters is controlled by the operator.

Eight hydraulic equalizing cylinders, two at each corner of the movable platen, are interconnected in closed-pipe circuits to combat unequal movement during vertical travel. Should unequal movement occur, pressure switches in the circuits automatically return the press to the open position. It cannot be closed until the cause of unequal movement is rectified.

Quench water is supplied by three 8000 gal/min pumps at 140 ft head and is fed to the spray pipes which are arranged in six sections located among the platens above and below the work. Each section is controlled by an air solenoid valve with an associated diaphragm-operated water control valve which is shown on the left of the illustration. The air pressure is controlled by the operator and this regulates the opening of the diaphragm valve and controls the supply of water to the sprays.

Tempering furnace

The tempering furnace has an internal width of 190 in. and a length of 200 ft. To provide additional normalizing facilities it will operate at the required higher temperature when necessary. In all general respects the furnace is similar to the hardening furnace but it differs in length and in details related to the zonal control of combustion and temperature.

Although normal work flow is towards the quench from both furnaces, it is possible to reverse its direction and this is particularly useful when plate is being normalized in both furnaces. It helps to relieve congestion at the quench car area. The furnace has therefore a run-out at each end to accommodate plates up to 45 ft long. It is controlled from the operating room in the same way as the hardening furnace.

Zone control, as in the hardening furnace, is obtained from air, gas, and oil valves with adjustable ports and these are pneumatically operated in tandem. The burners maintain combustion with 15–20% excess air and excellent uniformity of temperature is achieved at or around 680°C. Controllers of the pneumatic recording type with by-pass for manual control are provided. Temperature indicating controllers each operated from a single thermocouple located at one roll per zone afford protection against excessive roll temperature.

General information

The 'nerve centre' of the entire installation is the control room from which the operator can see the whole process of operation. Within it are housed the control desk, telephone, air conditioning unit, controllers for the hardening furnace, controllers for the tempering furnace, and the relay panel for the setting up and maintenance of the required operating conditions. On the mill floor and located near the control room is a 54-compartment motor control centre which contains the starters for all ac motors with the circuit breakers and transformers.

Centralized lubrication of the plant is provided from several hand-operated pumps with metering valves but the three transfer cars at the two extremities of the line are not connected. They are stationary for most of the time and as frequent lubrication is unnecessary they are equipped with an independent oiling system.

Continuous disc-type normalizing furnaces

(i)

Continuous normalizing furnaces up to 220 ft long are a necessity in certain plate mills of high productive capacity and these are usually of the roller conveyor type.

Furnaces of the disc-conveyor type are, however, in successful use for plates up to 8 ft wide, 60 ft long, and $\frac{1}{2}$–1 in. thick and can be used, when desired, for the stress relieving of thin plates which often have a tendency to harden during the last stages of rolling. A furnace for plates up to 12 ft wide and 2 in. thick is now being installed. Figure 19 shows the arrangement of one of the latest furnaces. A distinct advantage of the disc conveyor furnace is the small number of moving parts subject to heat. Only a small portion of the periphery of each rotating disc enters the furnace and its volume seldom exceeds 16 in.^{3}

The conveyor system consists of a series of shafts located below the furnace hearth and fitted with a number of wheels or discs about 40 in. dia. The rims of the discs pass through specially profiled slots in the monolithic hearth of the furnace and project about 2 in. into the chamber. The discs are arranged in staggered formation across the width of the furnace and interleave during rotation, so the distance between the supporting shafts is less than the diameter of the discs. When five discs are mounted on a shaft a 10-point plate support is provided by each pair of shafts, consequently very thin plates can be conveyed without difficulty. Plates of all thicknesses can be transported without damage to the hearth because the risk of 'dipping and digging' into the paving or ramming is almost completely eliminated. Although the furnace is long, the side clearances normally provided in short furnaces are adequate, and plates have little tendency to wander. Thousands of tons of plates have been normalized in furnaces of this type with only 7$\frac{1}{2}$ in. clearance at each side of the maximum width of plate conveyed.

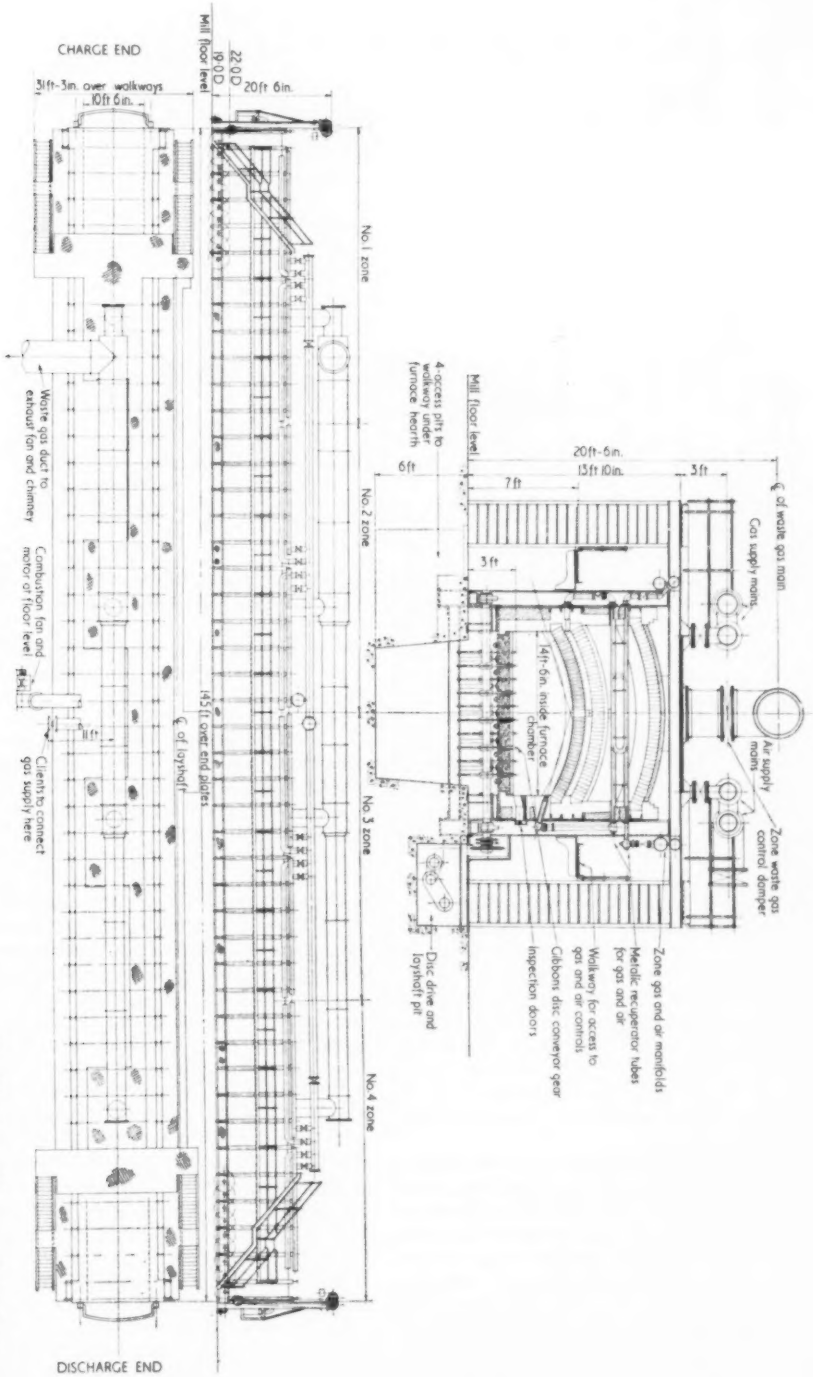
The discs are of composite construction with rims of heat-resisting steel incorporating a special provision for expansion. Facilities for shaft adjustment are provided should differential expansion occur in the shafts and furnace hearth.

The shafts are driven from one end and rotate in roller bearings mounted on brackets adjacent to the furnace buckstaves. The bearings at the driving end are of the locating type and those at the opposite end can float in the axial direction to take care of possible shaft expansion.

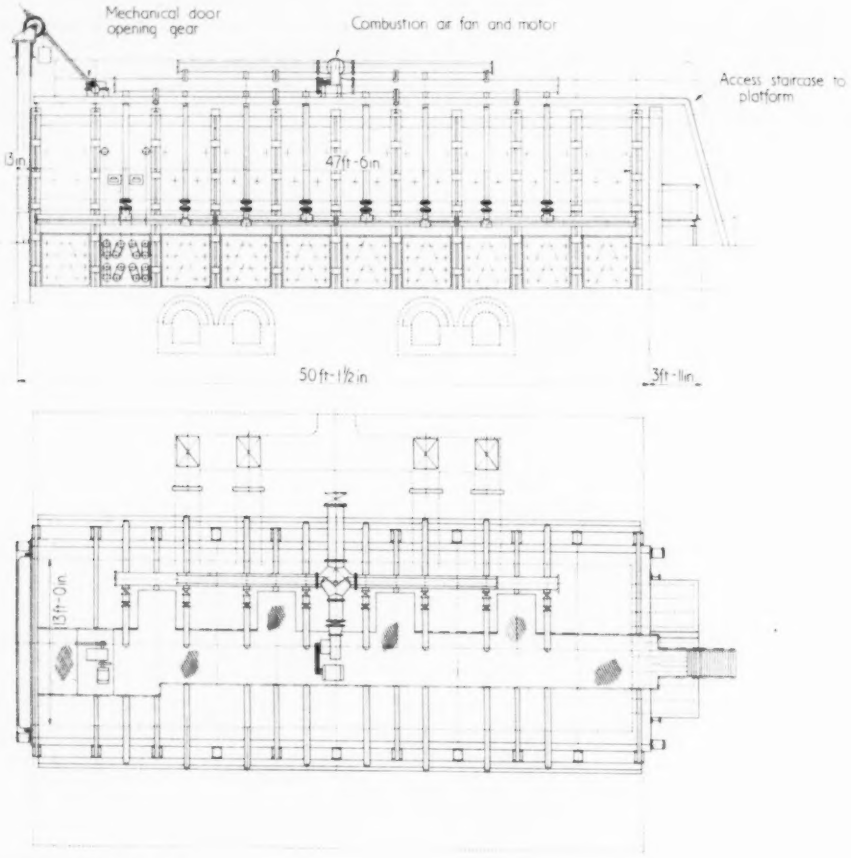
The disc shafts are interconnected and driven in groups of three or four by roller chains. Two such

groups are operated from a worm reduction gear with chain belt connection and form one unit of the complete drive mechanism. From 10 to 12 of these units are actuated by a common lay shaft extending along the side of the furnace and this is connected through a PIV gear to the main driving motor. The variable speed gear provides an adjustable conveying speed which ranges from 5 to 50 ft/min throughout the length of the furnace.

In a furnace 200 ft long, twelve disc shafts at each end of the chamber are intermittently rotated at increased speed to charge and discharge the plates as



19 ***Disc-type plate normalizing furnace***



20 *Batch-type normalizing furnace*

rapidly as possible. This is achieved by means of separate motors at the end sections of the layshaft. A differential system of couplings is employed to ensure that the end disc shafts revert to normal speed when the overdrive is cut out.

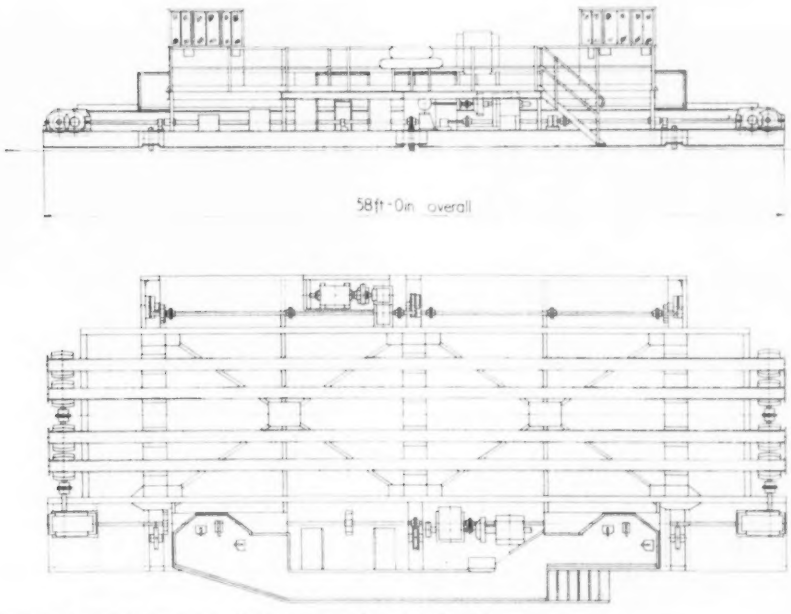
To prevent the skidding of fast moving plates on discs rotating at normal speed, seven disc shafts beyond the first twelve at the charging end of the furnace are fitted with free driving wheels. Inertial adjustment of the plate speed is then effectively accomplished. The seven shafts preceding the last twelve at the discharge end are similarly arranged. When the mangle speed exceeds the maximum speed of the twelve overdriven disc-shafts they are also equipped with free wheels.The freewheels are of the Morse cam and roller type, or alternatively of the sprag clutch type, mounted in the hubs of the chain sprockets.

These features ensure great flexibility in the furnace operation and minimize the effect of sudden shock loads on the discs and shafts. The life of the discs and shafts is extended and low maintenance costs are achieved. Skidding of the plates is effectively countered, scratching and marking is eliminated, and disc wear is reduced to a minimum. Two furnaces have been in continuous production for a combined period of 12 years and it has not yet been necessary to replace a single disc.

The discs normally rotate in one direction but their operation can be reversed. The furnace can then be used for the batch treatment of thick plates which, if continuously passed through the furnace at the minimum speed of travel available, would not be properly normalized. Plates ranging in thickness from $\frac{1}{8}$ to 2 in. or even more can then be treated provided the discs are suitably designed for the heaviest plate.

In the continuous disc-type normalizing furnaces already installed, blast-furnace gas or mixed gases are used with roof combustion. With this system preheated or cold gas is fed into the heating chamber through side inlets below the furnace arch. The arch itself incorporates a number of uniformly spaced holes of small and equal diameter through which the preheated air flows and mixes with the gaseous fuel below. Small downward flowing jets of flame are produced and these merge and form a 'blanket' of gases which completely covers the furnace hearth and ensures evenness of temperature across the width of the chamber. Preheated air is supplied under pressure from a fan at the recuperator and distributed to the chambers above the perforated arch.

The furnace is divided into four zones along its length and the gas, air, and waste-gas valves of each zone are automatically controlled. The temperature of each zone is controlled by thermocouples located underneath the plates. The gas valves are interconnected with the air valves and effective control of the



21 *Charging machine for batch-type normalizing furnace shown in Fig.20*

air/gas ratio is obtained. The furnace pressure is automatically controlled.

Air and gas when preheated are raised to 300°C in a recuperator located above the furnace. The steel tubes are calorized and accessible for easy withdrawal. The furnace is of insulated construction and when continuously operated on a lean fuel, such as blast-furnace gas, requires about 15 therms of heat per ton of plate normalized.

Batch-type normalizing furnaces with charging machines (i)

For normalizing plates more than 8–10 ft wide and for the thermal treatment of stainless-steel plates at temperatures ranging between 1080° and 1100°C batch-type furnaces with charging machines are widely used. The furnaces are usually arranged in batteries to suit production requirements, and are served by one or more charging machines with retractable arms which travel in slots in the hearth brickwork. The furnaces are available in different sizes up to 15 ft wide and 50 ft long.

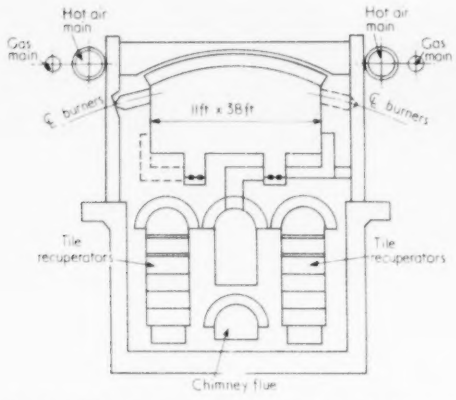
Two furnaces of the type shown in Fig.20 have recently been installed in a plate normalizing plant with provision for a third. The charging machine is of special construction and is shown in Fig.21. The furnaces have chambers 13 ft wide by 47 ft 3 in. long, and will accommodate plates up to 12 ft wide by 45 ft long, weighing 12 tons. The charging machine has four arms and the two inner arms will charge plates of smaller area up to 2 in. thick and 7½ tons in weight. When normalizing mild-steel plates, each furnace will maintain an output of 5 tons/h. Stainless-steel plates can be treated at 1080° to 1100°C.

The fuel is cold blast-furnace gas but richer gases or oil can readily be applied. Roof combustion is used. Four slots each 12 in. wide are provided in the hearths of the furnaces to accommodate the loading arms of the charging machine. For temperature control each furnace has three zones but each zone is subdivided into smaller zones with independent gas and air feeds.

The sub-zones of the furnaces have separate air and gas recuperators located in chambers below the hearths. These consist of double hairpin bend calorized steel tubes of sufficient number and size to preheat the air and gas to 300°C. The waste gases enter the recuperator chambers from equally spaced ports along the hearths of the furnaces. Gas and air supplies are controlled on the cold side.

The furnaces are well insulated and when regularly operated at full rating consume 14·5–16 therms of heat energy per ton of plate normalized. The doors are of fabricated construction, substantially braced to minimize warping and have sand seals along the top edges. They are electrically operated from the control platforms of the charging machine. The charging machine has special features and is capable of feeding a single or double row of furnaces. It travels on triple tracks and the wheels on the centre rail have doubled flanged tyres. The speed of travel is 100 ft/min under full load conditions. To widen the vision of the operator, dual control platforms are incorporated at each end of the machine and these are connected by a walkway.

The four charging arms have upper and lower carriages each constructed of 4 in. × 1 in. steel bars with spacers. The lower carriages have steel traverse wheels which run on tracks on the machine and also in the furnace. To centralize the arms in the furnace and cooling bank slots, vertical guide rollers are provided. Mounted between the bars of the upper carriages are several steel rollers which travel upon cast-steel inclined planes located between the bars of the lower carriages so that horizontal movement of the latter lifts the top carriages which are free to move in the vertical direction only. Horizontal movement of the top carriages is prevented by roller locks arranged to swing inwards between lugs attached to the outer sides



22 *Batch-type heat-treatment furnace with hearth slots to accommodate the arms of a charging machine*

of the bars. These locks are manually operated from the control platforms on the machine. Lifting, traversing, and lowering of the arms is achieved through the racks and pinions which are driven by a 15 hp motor. A speed change gear and slip coupling are incorporated in the drive which provides a traverse speed of 150 ft/min. When the arms approach the end of their forward stroke the speed of travel is automatically reduced.

(ii)

Figure 22 shows the cross-section of an end-charged heat-treatment furnace with a chamber 11 ft wide by 38 ft long. Two chases are provided in the hearth to accommodate the arms of the charging machine.

The charging machine is designed for cross travel and has the following characteristics:

Lift,	5¼ in. in 4·2 s
Long travel, ft/min	150
Cross travel, ft/min	150

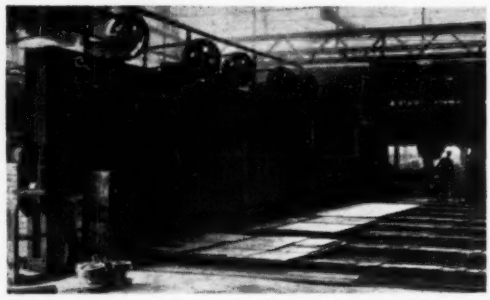
For interchangeability all the motors are rated 22 hp at 875 rev/min.

The furnace normally operates at a temperature of 850°C, and is fired with blast-furnace gas. It is equipped with burners of the turbulent quick mixing type which are located at a suitable height in the side walls of the furnace. The air for combustion is preheated in refractory recuperators below the furnace, and is supplied at a pressure of 6 in. wg by two fans. When desired the furnace can be boosted with coke-oven gas, but this is only necessary when stainless plates are being treated at a temperature of 1100°C.

The charging machine takes plates off a stillage and feeds them to the furnace. It also moves them through the furnace to the door at the opposite end, where they are singly discharged. The machine is designed to deposit the last plate clear of the discharge door.

The furnace normally heats ½-in. plates, and with a hearth coverage of 70% maintains an average production of 400 tons per week of 19 shifts. The average heat requirement is 20 therms/ton of plate, and the daily consumption of blast-furnace gas is about one million ft³.

Figure 23 shows a furnace with an effective hearth 50 ft wide by 15 ft deep. It was installed for the treatment of miscellaneous plates of different sizes and thicknesses. Single plates up to 12 ft wide by 45 ft long can be accommodated but the normal charge consists



23 *Batch-type heat-treatment furnace with charging machine*

of packs of smaller plates. The plates are 1 in. thick and upwards.

The charging machine is of special design and has eight arms which travel forward to charge the furnace, and backwards beyond the charging area in front of the furnace, to deposit treated plates on a roller table at the rear of the machine. Pairs of arms can be separately operated for the charging and withdrawal of individual plates or packs.

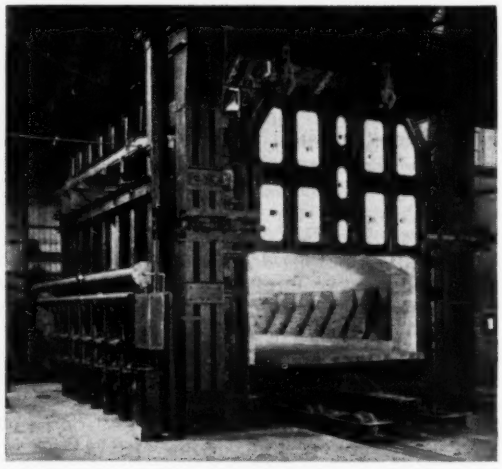
The furnace is fired with raw producer gas and the air for combustion is preheated in refractory recuperators. The air is naturally induced to special pressure burners in the 50 ft backwall of the furnace. Production averages about 4 tons of plates per hour on a coal consumption of 2·4 cwt/ton. Bare thermocouples placed on the plates within the furnaces show a high degree of temperature uniformity; the variation is less than 5°C.

Bogie furnaces for the batch treatment of plates

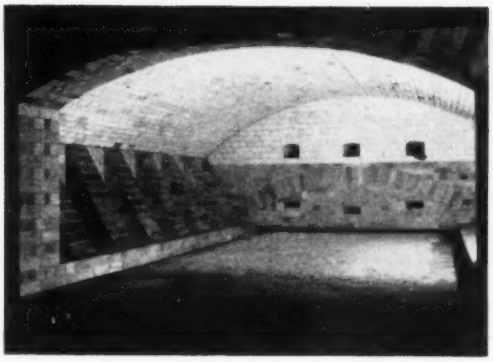
(i)

Furnaces of the bogie-type are extensively used for the thermal treatment of steel plates of miscellaneous sizes, qualities, and thicknesses.

Figure 24 shows a reversing-regenerative furnace which is fired with clean cold producer gas of 178–167 Btu/ft³. This furnace is one of a battery installed for the heat treatment of a wide range of steel products including thick slabs and plates. It has an effective hearth 8 ft 7 in. wide by 16 ft 4 in. long, and is capable



24 *Reversing regenerative bogie heat-treatment furnace*



25 *Reversing regenerative bogie heat-treatment furnace*

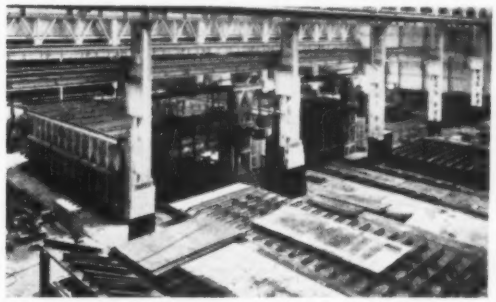
of operating at controlled temperatures between 250° and 1150°C.

The furnace is equipped with two sets of burners of special design with independent supplies of combustion air. One set is used for operating temperatures between 250° and 550°C and the other set for temperatures between 550° and 950°C. Both sets are simultaneously employed for temperatures between 950° and 1150°C. The furnace is automatically reversed and is equipped with instruments for the control of temperature, air/gas ratio, gas pressure, and furnace pressure.

The interior of the furnace chamber is shown in Fig.25. The crown and also the back wall down to a course 3 in. below the springer level of the crown are built with high-temperature insulating bricks. The consumption of fuel per ton of product depends upon the weight of the charge, and upon the temperature and duration of the heating cycle.

(ii)

The advantages of the bogie furnace for batch treatment of large plates are well known. Size is unrestricted and furnaces of modern design and construction meet every operating requirement. There is no impingement of flame upon the stock, the atmosphere is controlled and a positive pressure is maintained on the bogie hearth. Some furnaces are equipped with 'tempered flame' burners which utilize excess air to promote circulation. For the particular conditions under which excess air can be safely employed 'tempered flame' burners ensure great uniformity of temperature and assist in the maintenance of furnace pressure.



26 *Two bogie heat-treatment furnaces for steel plates*

Bogie furnaces for heat-treatment purposes are normally designed for a firing rate of 30000 Btu/ft³ of hearth per hour. Effective sealing of the charging doors and bogies is vitally important to furnace efficiency, and to the attainment of evenness of heat over the bogie hearth. Bogie operating speeds up to 80 ft/min have been adopted but such speeds are only necessary when the stock has to be quenched. Lower speeds are adequate for normal requirements and the haulage mechanisms are then less expensive. Figure 26 shows two bogie-type furnaces in a heat-treatment shop.

Thirty-ninth meeting of the Iron and Steel Engineers Group

The thirty-ninth meeting of the Iron and Steel Engineers Group will be held at the offices of the Institute, 4 Grosvenor Gardens, London SW1, on Wednesday and Thursday, 6 and 7 April 1960. Mr F. B. George will be in the Chair.

The meeting will be devoted to the discussion of four papers on the design and operation of heavy plate mills and their auxiliary equipment. The following is the programme:

Wednesday, 6 April

10.30 am–12.30 pm Presentation and discussion of the paper *Some Aspects of plate-mill design and layout*, by A. Marshall (Consett Iron Co. Ltd) (*JISI*, 1960, **194**, Feb., 240–248).

2.30–4.30 pm Presentation and discussion of the paper *The design of heavy plate mills*, by M. F. Dowding and C. Sturdy (Davy and United Engineering Co. Ltd). *Preprinted for meeting. Synopsis as follows:* Present-day requirements of metallurgical specification and dimensional tolerance have led to the introduction of new equipment in recent plate-mill installations. The problems set by customer requirements and the methods of achieving the necessary characteristics in the end products are discussed. Questions usually asked by steelmakers and the answers given by plant builders are considered, and general conclusions are drawn.

Thursday, 7 April

10.30 am–12.30 pm Presentation and discussion of the paper *Plate mill furnaces*, by The Society of Furnace Builders) (*JISI*, 1960, **194**, March, 365–383. This issue).

2.30–4.30 pm Presentation and discussion of a paper on *Developments in electrical equipment for reversing plate mills*, by H. S. Brown and A. P. Baines (English Electric Co. Ltd) (*JISI*, 1960, **194**, Feb., 225–240).

STAL *in English*

Number 9 (September 1959) of the cover-to-cover translation of the Russian journal *Stal'* has been published and subsequent issues should appear at about monthly intervals. Contents of nos. 9 and 10 are given below. Full details of subscriptions to *Stal in English* are available from the Secretary of The Iron and Steel Institute.

No. 9

The tenth anniversary of the Chinese People's Republic

IRONMAKING

Operating a large-capacity blast-furnace
Commissioning the second sinter plant of the Southern mining beneficiation combine
Discussion on the study of blast-furnace materials with radioactive isotopes
Automatic throttling of a large gas valve

STEELMAKING

Use of oxygen in the converter shop at Krivorozhstal'
Lining life in basic converters top-blown with oxygen
Investigation of the performance of a coke-oven gas fired 250-ton open-hearth furnace
Steel production in solid fuel fired furnaces
A sliding water-cooled spring-loaded seal for tilting furnaces
A device for determining the quantities and compositions of gases in molten metal or slag
A withdrawal stand for continuous steel casting plant

ELECTROMETALLURGY

Production of 38KhMYuA steel for internal combustion engines
Research at works laboratories in 1958

ROLLING AND TUBE PRODUCTION

Operation of an 850/730/530 continuous billet mill in the Chinese People's Republic
Optimum rolling schedule for ingots in a blooming mill
Atomic hydrogen in tube production
Velocite as a foaming agent in hydrochloric acid and chromium solutions
Effect of outer zones on resistance to deformation when rolling in grooves

METAL SCIENCE AND HEAT-TREATMENT

Effect of boron on the properties and heat-treatment of stainless spring steel
Stainless electric steel Kh12Yu
Shelling in rail heads
Prevention of metal crumbling in rail heads
Causes of the formation of surface defects on billets and rolled products
New alloys for thermistors

ECONOMICS AND ORGANIZATION

Discussion on the comparison of low-grade ferrosilicon production in blast and electric furnaces

GENERAL PROBLEMS

Kaolin refractories for soaking-pit lids

POWER AND PLANT

Preparation and use of shielding atmosphere from technically pure nitrogen
The hydraulic cleaning of water pipes

No. 10

IRONMAKING

Construction and use of belt conveyor for loading a blast-furnace skip
Material distribution at blast-furnace stockline
Foaming of metallurgical slags

STEELMAKING

Introduction of blown air into gas ports to intensify the melting process
The periscope method of measuring open-hearth furnace roof temperature
Use of natural gas in open-hearth furnaces
The recirculating recuperative steelmaking furnace

ELECTROMETALLURGY

Effect of vacuum treatment on the quality of 30KhGSNA and ShKh15 steels
A throwing shovel for charging free-flowing materials into electric furnaces
Arc heating of ingot feeder heads

FERROALLOYS

Methods of ferrosilicon production
A new method of preparing casting moulds and mould cores

ROLLING AND TUBE PRODUCTION

Development work in rolling ridged concrete reinforcement bar no.6
Improving sheet surface quality during pack rolling
Fluid-film bearings for vertical rolling-mill rolls
Friction coefficient and specific pressure when hot rolling in a vacuum
Ageing of the soap baths for lubricating phosphated pipes
Automatic ingot carrier control
Book review: 'Metal rolling'

METAL SCIENCE AND HEAT-TREATMENT

The effect of deoxaidation by silicocalcium on the properties of chromium–nickel–molybdenum steel
Spotty segregation in low-alloy steels
The influence of the original structure of transformer steels on their magnetic properties

ECONOMICS AND ORGANIZATION

The revaluation and assessment of deterioration of the iron and steel industry's capital goods
Discussion on the use of stand-by furnaces to increase labour productivity in open-hearth production

POWER AND PLANT

Purification of waste liquors from stainless steel pickling
An electrolyte for rapid tin plating

NEWS | *Announcements and News of Science and Industry*

THE IRON AND STEEL INSTITUTE

Special Meeting in Italy

The Council have accepted an invitation from the Associazione Italiana di Metallurgia to hold a joint meeting with them in Milan on Monday and Tuesday, **30 and 31 May 1960.** This joint meeting will form part of the Special Meeting of the Institute to be held in Italy from Sunday, **29 May,** to Saturday, **11 June 1960.**

The following is an outline of the programme of the meeting: the detailed programme will be given in the April issue of the *Journal*.

SECTION I—Milan and Rapallo or Santa Margherita

Sunday, 29 May

Arrive in Milan. Optional visit to Lake Como, with tea at Villa d'Este.

Monday, 30 May

Morning — Joint opening session with Associazione Italiana di Metallurgia, in the Museum of Science and Technology, Milan, followed by visit to museum.

Afternoon — Joint technical session with the AIM, at which the following papers will be presented:
New processes for the reduction of iron ores by A. Scortecci and A. Palazzi
Melting trials in electric and open-hearth furnaces on ferrous material produced by direct-reduction processes by O. Masi
OR
Works visits to either Breda Siderurgica S.p.A. or Stabilimenti di San Eustacchio S.p.A., Brescia.

Evening — Reception and cocktail party by invitation of the Lord Mayor of Milan.

Tuesday, 31 May

All day — Works visit to Dalmine S.p.A.
OR

Morning — Joint technical session at which the following papers will be presented:
Continuous casting of steel by M. Signora
Vacuum casting of steel by V. Scalise
OR
Works visit to Innocenti Società per l'Industria Metallurgica e Meccanica.

Afternoon — Works visit to Acciaierie e Ferriere Falck S.p.A.

Evening — Banquet by invitation of the Associazione Italiana di Metallurgia.

Wednesday, 1 June

All day — Works visits to:
FIAT S.p.A., Turin
OR
Nazionale Cogne S.p.A., Aosta.

Thursday, 2 June

Leave Milan for Rapallo or Santa Margherita.

Friday, 3 June

All day — Works visits to Cornigliano S.p.A. and SIAC (Società Italiana Acciaierie Cornigliano S.p.A.), near Genoa.

SECTION II—Rome

Saturday, 4 June

Leave Rapallo or Santa Margherita for Rome, with luncheon and sightseeing tour of Pisa en route.

Sunday, 5 June

Afternoon — Visit to Villa d'Este.

Monday, 6 June

Morning — Sightseeing tour of Vatican City.
Afternoon — Sightseeing tour of Ancient Rome.
Evening — Banquet by invitation of FINSIDER

Tuesday, 7 June

All day — Works visit to the Terni works of Società per l'Industria e l'Elettricità S.p.A.

SECTION III—Naples

Wednesday, 8 June

Leave Rome for Naples

Thursday, 9 June

All day — Works visit to the Bagnoli works of Ilva (Altiforni e Acciaierie d'Italia S.p.A.).

Friday, 10 June

All day — Visits to either Capri and Anacapri
OR
Pompeii, Amalfi, Positano, and Sorrento.

Saturday, 11 June

End of meeting.

For those who do not wish to take part in Section III of the meeting to Naples, a special three-day sightseeing tour has been arranged, visiting Assisi, Perugia, and Florence.

Full details of the meeting, together with registration forms, have been circulated to Members.

Annual General Meeting 1960

The Ninety-First Annual General Meeting of the Institute is being held in London from **3 to 5 May 1960.** The main technical session will be devoted to a symposium on the production of wide strip, at which papers from Italy, the Netherlands, the UK, and the USA are to be presented and discussed. There will also be a session devoted to electric-arc steelmaking. The full programme of the meeting appeared on p.249 of the February issue.

The Dinner for Members is being held at Grosvenor House, Park Lane, London W1, on the evening of Wednesday, **4 May**. The Rt Hon. Richard Wood, P.C., M.P., Minister of Power, will propose the toast of *The Iron and Steel Institute and Industry*.

Determination of gases in metals

A symposium on *The determination of gases in metals*, organized by the Society for Analytical Chemistry in conjunction with The Iron and Steel Institute and The Institute of Metals, is being held at Church House, Great Smith Street, London SW1 on Tuesday and Wednesday, **3–4 May 1960,** The meeting is open to members of the three societies and their guests. Those wishing to attend should apply to the Secretary of The Iron and Steel Institute, which is responsible for the organization of the meeting.

The full programme was published in the February issue, p.249.

NEWS OF MEMBERS

Mr **L. Badone** has joined the Etobicoke works of the Aluminum Company of Canada as staff metallurgist.

Mr **J. S. Blair** has been appointed production manager, coke, iron, and steel, at the Ebbw Vale Section of Richard Thomas and Baldwins Ltd.

Mr **C. W. J. Crawford** has left BISRA to become metallurgical editor of *Iron and Coal Trades Review*.

Mr **G. G. Davies** has been appointed general manager of the Redbourn section of Richard Thomas and Baldwins Ltd.

Mr **W. H. Day** has joined the boards of the Wellman Bibby Co. Ltd, and of the new company, Wellman Smith Owen (Furnaces) Ltd.

Dr **B. Edmondson** has joined the staff of the Central Electricity Generating Board, and is at present attached to the metallurgy division of the AERE, Harwell.

Mr **J. R. Edwards** has been appointed a director of Shepcote Lane Rolling Mills Ltd.

Mr **J. V. Emmons** has retired from active duties with the Cleveland Twist Drill Company but remains a member of the board. He is now acting as a metallurgical and research consultant.

Mr **J. Hewitt,** formerly of the research and development department of The United Steel Companies Ltd, has joined Steel, Peech and Tozer as senior research metallurgist.

Mr **Langton Highton** has been appointed a director of Barrow Ironworks Ltd, an ISHRA subsidiary, and succeeded Sir John Fisher as chairman on 1 March. He was also recently appointed a Deputy Lieutenant for the County of Cumberland.

Dr **T. P. Hoar** has been admitted to the degree of Doctor of Science in the University of Cambridge.

Mr **J. W. Holden,** managing director of Salem Engineering Co. Ltd, has been appointed technical consultant to the President of Salem Brosius Inc., Pittsburgh.

Mr **Frank Houghton** has retired from the post of sales director of Pickford, Holland and Co. Ltd, but is retaining his seat on the board in a consultative capacity.

Mr **F. J. Houghton** has been elected to the board of Pickford, Holland and Co. Ltd and appointed sales director.

Dr **J. P. Hugo** has joined the staff of the South African Atomic Energy Board, and will be working for the Board in the USA for about 18 months at the Argonne National Laboratory.

Mr **W. D. Jenkins** is now production manager, rolling mills, at the Ebbw Vale Section of Richard Thomas and Baldwins Ltd.

Mr **D. J. Jones** is now manager, steel and brickworks, at the Ebbw Vale Section of Richard Thomas and Baldwins Ltd.

Mr **N. R. Krishnaswamy** is now superintendent of development, Defence Metallurgical Research Laboratory, PO Ichapur-Nawabganj, West Bengal.

Mr **R. A. Lake** has been appointed assistant general manager (engineering) at the Ebbw Vale Section of Richard Thomas and Baldwins Ltd.

Mr **Richard Miles** has retired from the posts of chairman and managing director of Head Wrightson and Co. Ltd.

Mr **A. E. Pearson** has left Dorman Long (Steel) Ltd to become senior fuel engineer at the Spencer Works of Richard Thomas and Baldwins Ltd.

Mr **W. C. R. Penry** has been appointed manager, coke and iron, at the Ebbw Vale Section of Richard Thomas and Baldwins Ltd.

Mr **J. Ravenscroft** has left BISRA to become arc-furnace research assistant at Steel, Peech and Tozer.

Mr **D. Reilly** has left Guest Keen and Nettlefold Ltd to become cold-rolling mill manager at Steel, Peech and Tozer.

Mr **R. Stewartson** is now works manager of Guest Keen and Nettlefold (South Wales) Ltd.

Mr **L. G. Stock** is now manager of technical sales services (flat-rolled products) of Richard Thomas and Baldwins (Sales) Ltd.

Mr **B. Sweeney** has left the Permanent Magnet Association to become a senior investigator with the British Steel Castings Research Association.

Mr **G. Talbot** has been appointed managing director of Wellman Smith Owen (Furnaces) Ltd, a new subsidiary of the Wellman Smith Owen Engineering Corporation.

Mr **D. R. Thorneycroft** is now on the development staff, with special responsibility for welding, at the London Office of the Mond Nickel Co. Ltd.

Mr **H. J. Tucker** is now contracts and service manager of the Electric Resistance Furnace Co. Ltd.

Mr **H. W. A. Waring**, C.M.G., has been re-elected chairman of the Steel Committee of the Economic Commission for Europe.

Mr **C. D. Wattleworth** has been appointed a director of the new company, Wellman Smith Owen (Furnaces) Ltd.

Mr **D. H. Wilkinson** has joined Low Moor Alloy Steelworks Ltd.

Mr **F. Arnold Wilson** has been appointed foundry machinery adviser to the Bedewell division of Baker Perkins Ltd.

Dr **J. G. Wistreich** has been elected a Fellow of The Institution of Metallurgists.

Sir **John Wrightson**, BT., has succeeded Mr Richard Miles as chairman and managing director of Head Wrightson and Co. Ltd.

Mr **Peter Wrightson**, O.B.E., has been appointed vice-chairman and managing director of Head Wrightson and Co. Ltd.

Obituary

Mr **William Dewhurst** (*elected* 1949), of Sheffield, on 12 February 1960.

Mr **Richard Arthur Owen-Barnett** (*elected* 1954), of Newport, Mon., on 3 December 1959.

Señor **Arturo Rodriguez de la Peña**, L.I.M. (*elected* 1951), of Reinosa, Spain.

Correction

It was incorrectly stated in the December 1959 issue that Mr **Robert Barnaby** had joined the board of Brown Bayley Steels Ltd. Mr Barnaby has been managing director of this company for some time; his new appointment is to the board of the holding company, Brown Bayley Ltd.

AFFILIATED LOCAL SOCIETIES

Leeds Metallurgical Society

The officers and committee of the Society for the current session are:

President: Mr W. L. Bolton
1st Vice-President: Dr E. Simister
2nd Vice-President: Mr V. Dewhirst
Honorary Secretary: Dr P. R. Beeley
Honorary Treasurer: Mr A. Lenton
Committee: Dr W. R. Berry, Dr P. Feltham, Mr C. Breckon, Mr K. Neath, Mr K. Dobson, Mr C. V. Wilson
Past-Presidents: Mr A. Lenton, Mr P. Green, Mr K. Hill

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Additional Assistant Director

It was recently announced that Mr S. S. Carlisle, M.SC., A.M.I.E.E., had been appointed an Assistant Director of the British Iron and Steel Research Association. He will be especially concerned with the co-ordination of BISRA's work on automation and information handling; his work will include co-operation with laboratories and firms outside the Association, with a view to increasing the overall research and development effort devoted to automation in the steel industry.

Mr Carlisle graduated from the Queen's University, Belfast (College of Technology), in electrical engineering, and obtained the degree of M.Sc. in 1942. He spent four years during the war and after on the staff of the Director of Scientific Research, Admiralty, engaged on the development and trials of radar and gun-control equipment.

He joined BISRA in 1946, becoming head of the instruments section of the Physics Department in the following year; here he was specially concerned with the development of new measuring and control systems for furnaces, hot-strip width-measuring techniques, etc. He became head of the BISRA South Wales laboratories in 1954, and was responsible for the development of continuous strip processing in the field of tinplate and in the production of PVC-coated steel strip.

In 1958 Mr Carlisle returned to London to become head of the Physics Department. In May of last year he was a member of a delegation which visited the USSR under the auspices of the Institution of Electrical Engineers to study automation research and development.

INSTITUTION OF METALLURGISTS

London branch meeting

The London members of The Institution of Metallurgists are holding their spring meeting on Tuesday, 22 March, at Battersea College of Technology, Battersea Park Road, London SW11. Mr E. A. G. Liddiard, Director of Research, Fulmer Research Institute, is to give a lecture at 7 pm on *The expert witness*.

EDUCATION

Armourers' and Braziers' Research Fellowship

The Secretaries of the Royal Society are prepared to receive applications for the Armourers' and Braziers' Company Research Fellowship in Metallurgy.

The successful candidate will be required to enter upon and devote his whole time to research, which must be connected with base metals and alloys, and preferably those used in connexion with the ancient crafts of the Company of Armourers and Braziers.

The appointment will be for two years in the first instance, but may subsequently be extended for a maximum of five years. The stipend will be £1450 per annum, with annual increments of £100.

Applications should be received at the Royal Society, Burlington House, London W1, not later than 30 April 1960, and should be made on forms obtainable from the Assistant Secretary of the Society. Applicants must give three references and furnish particulars of their academic qualifications and of the research work already carried out by them. They should also give an outline of the research work they propose to undertake.

FORTHCOMING CONFERENCES

Materials handling

A two-day conference on materials handling, organized by the Willesden and Hendon Productivity Committee, is being held at Willesden Technical College on 22 and 23 March, 1960. Applications should be sent to Mr G. R. Lutner, S. Smith and Sons (England) Ltd, Waterloo Road, London NW2.

Ergonomics

The annual conference of the Ergonomics Research Society is being held at the University of Cambridge from 28 to 31 March 1960. The programme will include sessions on ergonomics in the armed forces, ergonomics in the Netherlands, and a symposium on factors in prolonged work, especially inspection.

Full details regarding the programme, accommodation, etc. may be obtained from Dr S. Griew, University of Bristol, Department of Psychology, 22 Berkeley Square, Bristol 8.

Welding

The spring meeting of the Institute of Welding is being held in Droitwich from 9 to 11 May 1960, and will be devoted to novel welding processes and metal spraying. In addition to technical sessions there will be a full programme of works visits and social functions. Details may be obtained from the Institute, 54 Princes Gate, Exhibition Road, London, SW7.

Reduction of iron ores

The electrothermics and metallurgy division of The Electrochemical Society is holding a three-day conference in Chicago on 2–5 May 1960. Over 20 papers from seven countries, including one from Dr R. Wild of BISRA, are to be presented, covering established and experimental methods of reduction. Full details of the conference may be obtained from Dr R. R. Rogers, Mines Branch, Department of Mines and Technical Surveys, 552 Booth Street, Ottawa, Canada.

Internal defects in steel

An all-day conference on internal defects in steel and methods of their assessment is being held by the West of Scotland Iron and Steel Institute at 39 Elmbank Crescent, Glasgow, on Friday, 13 May 1960. Applications for registration may be obtained from Mr P. W. Thomas, 39 Elmbank Crescent, Glasgow C2.

Mechanical handling

This year's Mechanical Handling Exhibition, organized by the journal *Mechanical Handling*, is being held at Earl's Court, London, from 3 to 13 May. Information may be obtained from the Organizer, Dorset House, Stamford Street, London SE1.

Powder metallurgy

An international powder metallurgy conference, sponsored by the Metal Powder Industries Federation and the Powder Metallurgy Committee of the Metallurgical Society of AIME is being held at the Hotel Biltmore, New York, from 13 to 15 June, 1960. Full details and registration forms may be obtained from the Metal Powder Industries Federation, 60 East 42nd Street, New York 17, NY, USA.

Fuel efficiency and power

A series of technical meetings is being arranged by a committee convened by the Institute of

Fuel in connexion with the Fuel Efficiency and Power for Industry Exhibition. The exhibition is being held at the National Hall, Olympia, London, from 27 April to 6 May, and the technical sessions will take place on 2 and 3 May in the Conference Hall at Olympia. Full details of the meetings, which are open to the public, may be obtained from the Institute of Fuel, 18 Devonshire Street, London W1.

Metallic corrosion

The First International Conference on Metallic Corrosion is to be held at the Imperial College of Science and Technology, London, from 10 to 15 April 1961. The papers will be divided into eight main sections:

1 Corrosion principles and fundamentals
2 Papers relating to particular metals
3 Papers relating to particular environments
4 Methods of protection
5 General
6 Economics and design
7 Methods of testing
8 Education

The scientific programme is being organized by a special committee under the chairmanship of Mr L. Kenworthy, chairman of the Corrosion Group of the Society of Chemical Industry. Full details of the programme, including works visits and social events, will be announced later.

Agglomeration

The various societies of the American Institute of Mining, Metallurgical, and Petroleum Engineers, have joined in sponsoring an International Symposium on Agglomeration (IGA), to be held in Philadelphia, Pa., on 12–14 April 1961. Full details will be announced shortly.

NEWS OF SCIENCE AND INDUSTRY

Contract news

An IBM Ramac computer has been ordered by Dorman Long (Steel) Ltd, to be used in the mill office for acknowledging customers' orders, production control, and invoicing.

Power plant and electrical equipment valued at £2 million, including two turbo-generators, a turbo-blower, a gas-fired boiler, feed heaters, condensers, and ancillary plant, and all the motors, switchgear, transformers, and cabling for auxiliary services, has been ordered by Colvilles Ltd for their Ravenscraig plant from *The General Electric Co. Ltd.*

The Brightside Foundry and Engineering Co. Ltd has received an order from Brymbo Steel Works Ltd to manufacture and install as main contractors a 32-in. blooming mill, in connexion with the second development scheme at Brymbo. *The English Electric Co. Ltd* is to supply the electrical equipment for the mill.

Contracts for the new Spencer works of Richard Thomas and Baldwins Ltd include an order for nearly £2¼ million worth of electrical equipment (including the main drives for the finishing train of the 68-in. hot strip mill) and one for nearly £3 million for blast-furnace gas-cleaning plant; the former has been awarded to *The General Electric Co. Ltd* and the latter to *Lodge-Cottrell Ltd.*

The Steel Company of Wales Ltd has placed an order with the *Head Wrightson Machine Co. Ltd* for the supply of a high-speed cut-up line for the Abbey Works, to deal with coils of cold-rolled strip weighing up to 56000 lb.

New company

EFCO Ltd and Stein and Atkinson Ltd have joined forces in a new company, to be known as Foundry and Metallurgical Equipment Ltd, with headquarters at 161 Queens Road, Weybridge, Surrey. This company will design, manufacture, and supply an extensive range of foundry equipment, including gas- and oil-fired crucible melting furnaces, gas-, electric-, and oil-fired annealing furnaces, core stoves, etc. The directors of the new company are Mr D. F. Campbell (*chairman*), Mr C. J. S. Atkinson, Mr J. A. Monks, and Mr C. H. Williams; the consulting metallurgist is Dr A. G. Robiette.

Industrial archaeology

The Council for British Archaeology has recently formed a research committee on the subject of the archaeology of the Industrial Revolution, which includes archaeologists, geologists, architects, technologists, and others interested in surviving industrial remains of the 17th to 19th centuries. It is hoped that the committee will be able to draw into a programme of planned recording and research the wide variety of interests in the subject.

The committee's first project was a public conference, held on 12 December at the London School of Hygiene and Tropical Medicine, Keppel Street, London WC1. The meeting included papers on recent research, on the problems awaiting study, and on the methods required. Further details may be obtained from the CBA, 10 Bolton Gardens, London, SW5.

Pilot plants in metallurgical research and development

A symposium on *Pilot plants in metallurgical research and development* was held at the National Metallurgical Laboratory, Jamshedpur, India, on 15–18 February, 1960. Professor M. S. Thacker, Director-General of Scientific and Industrial Research at New Delhi opened the symposium on 15 February, and Sir J. J. Ghandy, Director-in-Charge, The Tat Iron and Steel Co. Ltd and Chairman of the Executive Council of the National Metallurgical Laboratory presided.

The object of the symposium, which attracted delegates from all over the world, was to focus attention on the application of pilot plants in metallurgical research and development and to emphasize the value of undertaking such pilot-plant work in various aspects of the metallurgical and minerals industries.

BISF safety film

Mountain climbing at first sight might not seem to have much connexion with safety in iron and steelworks. However, this subject has been used with great skill in the latest film from the British Iron and Steel Federation. *Hazard* is a colour film running for 36 minutes which uses an incident on a mountain in the Dolomites to point a moral. It is less concerned with specific safety practices than with the wider attitude to safety. Taking risks can become a habit, but the observation of safe practices can equally become a habit, and one that is more likely to produce rewarding results.

The film is brilliantly produced (Geoffrey Sumner) and directed (Tom Stobart). It is available on free loan from the BISF Film Library, Steel House, Tothill Street, London SW1.

Continuous casting agreement

Continuous Casting Co. Ltd of Weybridge have concluded an agreement for technical collaboration with Low Moor Alloy Steelworks Ltd of Bradford. Continuous Casting Co. Ltd is a licensee for the BISRA process, and Low Moor has developed in its own works the continuous casting of stainless and alloy steel slabs, blooms, and billets.

New head office for United Steel

The head office of the United Steel Companies Ltd was moved recently to The Mount, Broomhill, Sheffield 10, a short distance from the former buildings in Westbourne Road.

Further changes for SPT

Following the recent announcement that the melting shops of Steel, Peech and Tozer were to be converted entirely to electric furnace production comes the news that the semi-continuous bar mill, now nearly 40 years old, is to be modernized at a cost of over £400000. Work has begun on the scheme, which is scheduled for completion in August this year.

The modernization will take the form of the replacement of the existing single 3000-hp drive by a number of separate variable-speed dc motors totalling 3400 hp and the renewal of some of the mill stands. Main contractors are the Brightside Foundry and Engineering Co. Ltd, the electrical equipment being supplied by AEI Ltd.

New Wellman subsidiary

Owing to the expansion of its furnace building and contracting activities, particularly in the field of oxygen steelmaking processes, the Wellman Smith Owen Engineering Corporation Ltd has decided to segregate and operate the sales organization of its furnace building and contracting department as a separate subsidiary company, to be known as Wellman Smith Owen (Furnaces) Ltd. Mr G. Talbot, manager of the former furnace department, has been appointed managing director of the new company, and Mr C. C. Wattleworth has been appointed to its board. The address of the new company is the same as that of the parent company, Parnell House, Wilton Road, London SW1.

First Durgapur furnace commissioned

The President of India, Mr Rajendra Prasad, officially opened the blast-furnace plant at the Durgapur Steelworks, West Bengal, on 29 December 1959. The first blast-furnace has been blown in, and in addition the coke ovens, coal washery, and by-products plant are now in operation.

INDUSTRIAL PUBLICATIONS RECEIVED

Catalogue No.59 is now available from John Shaw and Sons (Salford) Ltd, hydraulic engineers.

Nu-Swift have produced an excellent catalogue of fire-fighting equipment.

Leaflets M.6A and M.9B from Metalectric Furnaces Ltd deal with continuous bright annealing and standard high-temperature furnaces respectively, and leaflet M.18A with electrode salt baths.

Midland Heating and Ventilation Co. Ltd have issued three brochures on cooling towers.

The case-hardening of nickel alloy steels is the title of the latest publication from the Mond Nickel Co. Ltd.

CHANGES OF ADDRESS

The Institute of British Foundrymen has moved from Manchester to 14 Pall Mall, London SW1 (WHItehall 7141).

The London Office of the British Welding Research Association has moved to 19 Fitzroy Square, London W1 (EUSton 9595/6).

Davy British Oxygen Ltd has moved to Suffolk House, Suffolk Road, Sheffield 2 (telephone 21307, 24516).

The new offices of Stein and Atkinson Ltd are at Westminster House, Kew Road, Richmond, Surrey.

DIARY

1 Mar. SHEFFIELD METALLURGICAL ASSOCIATION and SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—*Cold forging and extrusion of steel*, by Dr J. B. Hawkyard and N. S. Angus—BISRA, Hoyle Street, Sheffield, 7 pm.

2 Mar. BRITISH NUCLEAR ENERGY CONFERENCE—Informal discussion on education and training in nuclear power development—Institution of Mechanical Engineers, 1 Birdcage Walk, London SW1, 6 pm.

2 Mar. SWANSEA AND DISTRICT METALLURGICAL SOCIETY—*Alternatives to the open-hearth process*, by Dr

A. J. Kesterton—Central Library, Swansea, 6.45 pm.

3 Mar. LIVERPOOL METALLURGICAL SOCIETY—*Semi-conductors*, by R. P. Chasmar—Department of Metallurgy, Liverpool University, 7 pm.

5 Mar. LIVERPOOL METALLURGICAL SOCIETY—Annual conversazione—University Club, Liverpool.

7 Mar. CLEVELAND INSTITUTE OF ENGINEERS—*An aspect of nuclear energy applied to power stations*, by F. Carr—Cleveland Scientific and Technical Institution, Middlesbrough, 6.30 pm.

7 Mar. SHEFFIELD METALLURGICAL ASSOCIATION and INSTITUTE OF BRITISH FOUNDRYMEN (Sheffield Branch)—*Bonding clays: recent work and ideas*, by Professor A. L. Roberts—Sheffield College of Commerce and Technology, Pond Street, Sheffield, 7 pm.

8 Mar. SHEFFIELD METALLURGICAL ASSOCIATION—Biennial dinner—Royal Victoria Station Hotel.

9 Mar. MANCHESTER METALLURGICAL SOCIETY—*Metallurgical aspects of fuel elements for nuclear reactors*, by Dr H. M. Finniston—Central Library, Manchester, 6.30 pm.

9 Mar. NORTH WALES METALLURGICAL SOCIETY—*The physical chemistry of steelmaking*, by Dr J. Pearson—Flintshire Technical College, Connah's Quay, 7 pm.

10 Mar. LEEDS METALLURGICAL SOCIETY—*Unpopular methods of establishing equilibrium diagrams*, by Dr H. W. Rayson—6.30 pm.

14 Mar. LINCOLNSHIRE IRON AND STEEL INSTITUTE—Annual General Meeting—North Lindsey Technical College, Scunthorpe, 7.30 pm.

14 Mar. SHEFFIELD METALLURGICAL ASSOCIATION and SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—Symposium on *Hot extrusion of steel*.

16 Mar. LIVERPOOL METALLURGICAL SOCIETY—Visit to Pilkington Bros. Ltd, St Helens.

16 Mar. SOCIETY OF CHEMICAL INDUSTRY (Corrosion Group)—*The mechanism of inhibition in neutral aqueous solutions*, by D. M. Brasher—14 Belgrave Square, London SW1, 6 pm.

17 Mar. NEWPORT AND DISTRICT METALLURGICAL SOCIETY—*Manufacture of tonnage oxygen and its influence on steelmaking*, by J. L. Harrison—Whitehead Institute, Cardiff, 7 pm.

17 Mar. STAFFORDSHIRE IRON AND STEEL INSTITUTE—*The use of computers in the steel industry*, by N. C. Pollock, M.B.E.—Station Hotel, Dudley, 7.30 pm.

18 Mar. WEST OF SCOTLAND IRON AND STEEL INSTITUTE—*Technical factors in the production of iron by methods other than the blast-furnace*, by Dr J. Taylor—39 Elmbank Crescent, Glasgow, 6.45 pm.

19 Mar. SWANSEA AND DISTRICT METALLURGICAL SOCIETY—Annual dinner—Mackworth Hotel, Swansea.

21–22 Mar. INSTITUTION OF MECHANICAL ENGINEERS—Discussion on *The computer in production*—1 Birdcage Walk, London SW1.

22–24 Mar. ROYAL INSTITUTION OF NAVAL ARCHITECTS—Spring Meeting—10 Upper Belgrave Street, London SW1.

22 Mar. SHEFFIELD METALLURGICAL ASSOCIATION (Methods of Analysis Group)—*Problems and progress in the analysis of slags and refractories*, by D. Shireby—BISRA, Hoyle Street, Sheffield, 7 pm.

24 Mar. EBBW VALE METALLURGICAL SOCIETY and THE IRON AND STEEL INSTITUTE—*The L–D steelmaking process*, by Dr O. Cuscoleca—RTB Club and Institute, 7 pm.

28–31 Mar. ERGONOMICS RESEARCH SOCIETY—Annual conference—Cambridge

29 Mar.–1 Apr. BRITISH WELDING RESEARCH ASSOCIATION and ENGINEERING DEPARTMENT, CAMBRIDGE UNIVERSITY—Symposium on *Fatigue of welded structures*—Trumpington Street, Cambridge.

29–31 Mar. INSTITUTE OF METALS—Spring Meeting—Church House, Great Smith Street, London SW1.

29 Mar. SHEFFIELD METALLURGICAL ASSOCIATION—*Corrosion – the £600 million problem*, by A. M. Edwards—BISRA, Hoyle Street, Sheffield, 7 pm.

30 Mar. INSTITUTE OF METALS—Informal discussion on *New aspects of the electron theory of metals*—Hoare Memorial Hall, Church House, London SW1, 2.30 pm.

31 Mar. INSTITUTE OF METALS—Dinner and Dance—Grosvenor House, Park Lane, London W1, 7.30 pm.

4 Apr. CLEVELAND INSTITUTION OF ENGINEERS—*A modern plate mill*, by M. F. Dowding—Cleveland Scientific and Technical Institution, Middlesbrough, 6.30 pm.

4–5 Apr. CORROSION SCIENCE SOCIETY—First meeting—Battersea College of Technology, London SW11.

6–7 Apr. THE IRON AND STEEL INSTITUTE (Engineers Group)—Meeting on plate mills—4 Grosvenor Gardens, London SW1.

6 Apr. SOCIETY OF CHEMICAL INDUSTRY (Corrosion Group)—*The presentation of corrosion information*, by Dr J. W. Jenkin—14 Belgrave Square, London SW1, 6 pm.

7 Apr. LEEDS METALLURGICAL SOCIETY—*Metallurgical research in the DSIR*, by Dr N. P. Allen, F.R.S.—6.30 pm.

7 Apr. LIVERPOOL METALLURGICAL SOCIETY—*The examination of irradiated fuel elements*, by G. B. Greenhough, and 12th Annual General Meeting—Department of Metallurgy, Liverpool University, 7 pm.

8 Apr. WEST OF SCOTLAND IRON AND STEEL INSTITUTE—Annual General Meeting—39 Elmbank Crescent, Glasgow, 6.45 pm.

12 Apr. POWDER METALLURGY JOINT GROUP—Symposium on *Continuous processing in powder metallurgy*—Hoare Memorial Hall, Church House, London SW1, 10.30 am.

BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on p.252 of the February 1960 issue of the *Journal*:

Appropriate depth of hardening in surface hardened gear teeth.
GLAUBITZ, H., *ZVDI*, 1958, Feb. 21, pp.216–226. (£8 15*s*. 0*d*.) [**1342**

Studies on the hot working strength of steels. II. High temperature deformation strength of various steels.
INOUYE, K., *Tetsu to Hagane*, 1955, June, pp.593–601. (£8) [**1430**

Equilibria between iron and line-containing phosphate slags.
TRÖMEL, G., and FRITZE, H. W., *Arch. Eisenhütt.*, 1959, Aug., pp.461–472. (£7) [**1462**

Cold impact extrusion of steel.
EBERSPÄCHER, H., *Werkstatt u. Betrieb*, 1958, Oct., pp.605–608. (£3) [**1467**

Hydrodynamics of molten steel when teeming. II.
KOIKE, Y., *Tetsu to Hagane*, 1958, March, pp.260–262. (£4 15*s*. 0*d*.) [**1477**

Measuring and control plant at the experimental converter of Phoenix Rheinrohr at Duisburg–Ruhrort.
EWE, K., *Regelungstechnik*, 1959, July, pp.248–253 (£3 10*s*. 0*d*.) [**1485**

Tests to determine roll forces and power requirements in a Mannesmann oblique rolling mill.
GELEJI, A., *et al.*, *Stahl u. Eisen*, 1959, Sept. 17, pp.1352–1356. (£3 15*s*. 0*d*.) [**1490**

The hot torsion test as a method of assessment of the forgeability of steel.
WALQUIST, G., and J.-C. CARLEN, *Jernkont. Ann.*, 1959, (1), pp.1–28. (£7 15*s*. 0*d*.) [**1495**

The plastic behaviour of lime mortar.
BACKMAN, A., *Zement-Kalk-Gips*, 1959, (10), pp.449–456. (£5 15*s*. 0*d*.) [**1500**

The reactive capacity of blast-furnace slags for sulphated metallurgical cement.
TSUMURA, S., *Zement-Kalk-Gips*, 1959, Sept., pp.392–408. (£7 10*s*. 0*d*.) [**1501**

Selection of blowers for cupolas.
ANON, *J. d'Inf. Tech. Ind. Fonderie*, 1959, Jan., pp.1–3. (£1 15*s*. 0*d*.) [**1502**

The use of carbon steel for the production of heat-treated (quenched and tempered) API–E boring tubes.
ŠEJNOHA, R., and ŠMID, V., *Hutnické Listy* (Prague), 1958, (10), pp.878–881. (£4 10*s*. 0*d*.) [**1505**

Modification of carbon extraction replicas for austenitic steels.
HRIVNAK, I., *Hutnické Listy* (Prague), 1959, (3), pp.211–214. (£4 15*s*. 0*d*.) [**1508**

The use of electron microscopy for the study of kinetic phenomena in previously selected areas.
MOLČIK, M., and KLESNIL, M., *Hutnické Listy* (Prague), 1959, (8), 688–692. (£5 15*s*. 0*d*.) [**1510**

Contribution to the reduction behaviour of several oxides and oxygen compounds in fractional hot vacuum extraction in a carbon crucible.
SCHENCK, H., and UNGER, K.-D., *Arch. Eisenhütt.*, 1959, Sept., pp.549–552. (£3) [**1523**

Stainless steel bolts for aircraft.
RICHTER, E., *Luftfahrttechnik*, 1959, Feb. 15, pp.58–60. (£3) [**1525**

Observation of the state of the bath and slag during the refining of steel in the basic converter
VÖGE, H., and EICKWORTH, E., *Stahl u. Eisen*. 1959, Nov. 12, pp.1715–1722. (£4 10*s*.) [**1527**

Problems relating to wheels.
RAVENET, P., and BOULEY, J., *Rev. Gén. Chemins de Fer*, 1959, Nov., 684–686. (£2 5*s*.) [**1536**

Problems relating to the braking of trains.
LAPLAICHE, M., *Rev. Gén. Chemins de Fer*, 1959, Nov., pp.687–697. (£6) [**1537**

Effect of steel composition on hot tearing in castings.
TRUBITSYN, N. A., and BIDULYA, P. N., *Lit. Proizv.*, 1958, (6), pp.22–26. (£5 15*s*. 0*d*.) [**1538**

Investigations of a new kind of secondary recrystallization in iron–3% silicon alloy.
DETERT, K., *Acta Metallurgica*, 1959, Sept., pp.589–598. (£5 5*s*. 0*d*.) [**1543**

The influence of finely dispersed precipitates on the coercive force of transformer sheets.
WAGNER, R., *Acta Metallurgica*, 1959, July, p.523. (£2) [**1549**

Fatigue cracks in composite back-up rolls for cold mills.
FUNKE, P., *Stahl u. Eisen*, 1959, Oct. 1, pp.1430–1431. (£1 10*s*. 0*d*.) [**1560**

The influence of the properties of the constituents of the blend on the fissuring of coke.
LOISON, R., and BOYER, A. F., Centenary Congress of the Société de l'Industrie Minérale, Paris, June, 1955, Paper SA 1, pp.1–6. (£5 10*s*.) [**1574**

Can fissuring of coke be forecast in the control laboratory?
BOYER, A. F., and LAHOUSTE, J., *Indust. Chim. belg.*, 27th Internat. Congress Ind. Chem., 1954, Sept., Special No., pp.29–32. (£2 5*s*. 0*d*.) [**1575**

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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ABSTRACTS

These abstracts are also available on index cards in advance of publication in the *Journal*, each abstract being classified under the Universal Decimal system (UDC). Details and subscription notes can be obtained from the Secretary, The Iron and Steel Institute.

MINERAL RESOURCES

Raw materials—iron and other ores C. J. J. R. Raju, S. N. Sircar, and V. K. Agashe (*Tisco*, 1959, **6**, April, 69–90) An account of the sources of raw materials and mining methods, crushing plant, and loading flowsheets is given (referring to Tata).

Old zirconium–ilmenite alluvials in the Meso-Cainozoic sedimentations in western Siberia L. V. Eselevich, A. I. Lisitsyn, N. S. Puchin, and V. I. Pyatnov (*Razvedka i okhrana Nedr*, 1959, (4), 1–4) In northern and western Siberia deposits have been found. As a result of prospecting in 1956–7 the Tugansk zirconium–ilmenite deposits have been opened up. These are situated in a region where hydroelectric power stations are under construction and where the deposits may be worked open cast. The quartz sand mixed in the layers can be easily separated and used for glass production and as moulding material for the foundry industry.

Experiences in prospecting for rich iron ore in the KMA S. I. Chaikin (*Razvedka i Okhrana Nedr*, 1959, (5), 8–13) A report on discovered deposits and their geographical location. Suggestions are made for a wider application of gravitational and seismic methods of prospecting this very rich region.

New rich iron deposits in the Kursk Magnetic Anomaly (KMA) A. D. Buketov (*Razvedka i Okhrana Nedr*, 1959, (5), 5–7) New deposits have been discovered which, on a rough calculation, would amount to about 400 mil. tons with an average content of 56·6% iron, 4·39%Si, 5·65% insoluble matter, and 9·37% loss on roasting.

Cerro de Mercado, Mexico M. S. Albans (*Min. Mag.*, 1959, **100**, June, 334–336) A brief illustrated account of mining methods and equipment at this iron mine.

ORES—MINING AND TREATMENT

Studies on the oxidation of pyrite. III. The intermediate products in the oxidation of pyrite K. Nishihara and Y. Kondo (*Mem. Fac. Eng. Kyoto Univ.*, 1959, **21**, April, 214–228) Magnetic, thermomagnetic and X-ray studies were made. Magnetization intensity passes through a maximum on oxidation, the maximum being higher at low partial O_2 pressures. Samples from Herreshoff furnaces were also examined. A lower sulphide of indefinite composition, Fe_3O_4 and Fe_2O_3 are formed in succession.

Ore-microscopic studies of the manganese ore-minerals of old M.P. I. Dongribuzurg, Bkandara District S. P. Deshpande (*Proc. Indian Acad. Sci.*, 1959, **49A**, March, 165–173) Constituents are identified, X-ray studies of an unidentified constituent are in progress.

Huge ore-storage bin for Whyalla G. W. Elliott, (*BHP Rev.*, 1958, **36**, Dec., 22–24) A 40 000-t capacity bin with its conveyor system is described.

Formulae for the valuation of ores and their representation by means of nomograms P. Legoux (*Ann. Mines*, 1959, May, 308–312) Three nomograms are constructed, referring to continental and British practice for dry and moist ores.

Variations in the iron content of extracted ores, depending on the method of their preparation and on the technical processes V. T. Lozovoi (*Razvedka i Okhrana Nedr*, 1959, (4), 50–52) The reduction of the iron content in the ore is due to the unsatisfactory choice and application of the methods of preparation. When using compartment methods, a reduction in the iron content must be attributed to incorrect mining operations and to the inclusion of barren rock.

Pneumatic conveyors solve sticky problem in Taconite processing (*Steel*, 1959, **145**, July 13, 108–110) Pneumatic systems for conveying bentonite, soda ash, and pulverised coal at a taconite pelletizing plant are described. The bentonite is first handled in an 'Airslide' conveyor in which air entering through a permeable diaphragm along the length of the conveyor keeps the powder fluid. This system and the 'Airveyor' system are controlled from a central panel.—D. L. C. F.

Colloque sur l'enrichissement des minerais de fer, held at CESSID, Metz, Oct. 8, 1957 (*Centre Doc. Sidérurg.*, 1958, Aug.) **Conference 1. The beneficiation of iron ores in the world** J. Astier (5–13) Development of world trade in iron ore, particularly maritime trade, is discussed, and the development of methods for the beneficiation of low-grade iron ores is reviewed, under the headings of magnetites, easily 'washable' ores, and fine-structure hematites and limonites. **Conference 2A. Beneficiation of iron ores in the United States** F. W. Bowdish (16–22) A detailed account is given of ore treatment in the Lake Superior area, with a summarized review of methods in other USA deposits (13 refs). **Conference No.2B. Development of ore beneficiation in USSR** M. Kunicki (24–29) The known deposits and reserves in USSR are enumerated, the principal concentration techniques used are described, and an account is given of the methods used in the Kertch, Krivoi-Rog, KMA, and Ural basins. **Conference No.2C. Developments in ore beneficiation in Scandinavia** M. Febve (50–54) Methods of ore concentration, and the development of the iron and steel industry in Scandinavia are outlined. **Conference No.2D. Development of ore beneficiation in West Germany** M. Pasquet (55–64) The types of German ore deposits are described and the historical development of ore concentration in Germany is discussed. **Conference No.3. New tendencies relating to the beneficiation of ores, as reported at the Stockholm Congress (Sept. 1957)** P. Javelle (65–70) A general survey of modern methods of crushing, classification, and concentration of ores. **Conference No.4. Special problems of the beneficiation of Lorraine ores** P. Guinard (71–74) The development of research into the beneficiation of Lorraine ores, the special problems involved and a summary of the main features of the Lorraine deposits are given. **Conference No.5. Beneficiation of Lorraine ores. Investigations carried out between 1931 and 1939** L. Boileau (75–90) The petrology, methods of classification with a view to concentration, and beneficiation experiments on oolitic, particularly Lorraine ores are described. **Conference No.6. IRSID projects in connection with the concentration of Lorraine ores** P. Emery (91–105) An historical survey is given of the development of research into the concentration of Lorraine ores, and is followed by a survey of the main techniques used. **Conference No.7. High-intensity dry magnetic separation. Principles and equipment** J. de Robert (107–112) The principles governing the use of high-intensity magnetic separation for paramagnetic and weakly ferromagnetic materials are discussed, equipment is described and economic factors are considered. **Conference No.8. Concentration of Lorraine ores by high-intensity magnetic separation. Eventual applications to industrial practice** L. Forichon, P. Javello, M. Pasquet, and J. de Robert (113–124) Results of trials carried out in the high-intensity dry magnetic concentration of Lorraine ores are described, and a detailed survey of technical and economic data concerning the possible application of the process to a Lorraine plant treating 2000 tonnes/day is given.

Sinter-plant assessment trials at Barrow Ironworks Ltd D. F. Ball (*JISI*, 1960, **194**, March, 351–360) [This issue].

Nodulizing finely crushed concentrates (*Metallurg*, 1959, (6), 39–40) A general review of the processes in use abroad, specially in USA, Germany, and England with special references to the article in *Mining Engineering*, 1958, (3).

Burning of pellets by gas I. I. Rovenskii (*Metallurg*, 1959, (9), 7–9) A review of Russian experiments is given using a mixture of propane and butane having a calorific power of 25000 Kcal/m³ in which combustion was affected with considerable excess air and an oxidizing atmosphere was created. The amount of free oxygen in the waste gases was 7–8% the FeO content of the pellets being 1·6–3·6%. The reducibility of such pellets made on a sinter strand is 1½ times as high as that of a product produced in a shaft furnace.—R.S.

On the swelling of iron oxide and its compounds during heating E. K. Keler and A. I. Leonov (*Ogneupory*, 1959, (5), 225–231) On heating specimens of pure oxides (Fe_2O_3, CuO, Co_3O_4) and also mixtures of 33·33 mol.% Fe_2O_3 with 66·66 mol% Cr_2O_3 to temperatures at which the dissociation pressure exceeds the partial pressures of the oxygen in the gaseous phase swelling, cracking, and a reduction in strength of the specimens is observed. Experiments show that additions of TiO_2 cause the formation of a liquid phase, increase the dissociation temperature of iron oxide and reduce or eliminate swelling.

FUEL—PREPARATION, PROPERTIES, AND USES

Coal preparation in France (*Rev. Ind. Min.*, 1959, Special No., May 15, pp.163) Document SIM. L3. **Introduction** M. A. Terra. **Preparation of run-of-the-mine coal prior to washing** A. Luscher and M. Devos. **Screening, desliming, dedusting** J. Turpin and R. Hamant. **Preparation of coal over 6 mm** L. Pozzetto. **Washing of fine coal below 6–10 mm** H. Aubois, M. Jean, and A. Plessis. **Treatment of slurry** R. Veillet and A. Pinçon. **General organization of washeries, washing costs, capital expenditure** R. Huchet.

Heating operation of coke ovens A. Nishio (*Tetsu to Hagane*, 1959, **45,** May, 542–556) A review, dealing with methods of operation, theoretical formulae, temp. distribution, etc. (15 refs).—K.E.J.

Improving the preparation of coke fines V. V. Vinogradov (*Metallurg*, 1959, (3), 3–4) At the Mundybashka a preliminary crushing operation was introduced. A hammer mill was used so as not to overcrush the coke, because should the fraction 0·5–0 mm be appreciable in quantity, its combustion deteriorates, which lowers the quality of the agglomerate. Details of the apparatus are supplied with the layout and it is claimed that it ensures an average content with 3–0 mm grain size of 94%.

Cooling systems in the coking and gas industries. 3. Which system to choose D. J. Tow (*Coke Gas*, 1959, **21,** July, 281–282, 285).

A survey of the coke oven effluent problem. Interim report (*BCRA*, 1956, May, pp.19) Research work in progress on the various biological, chemical, and physical methods is briefly outlined.

Biological processes and the coke oven effluent problem. Interim report, part I (*BCRA*, 1957, Oct., pp.28) The principles of biological treatment are set out with special reference to coke oven effluents.

Stream pollution and the coke oven effluent problem. Interim report (*BCRA*, 1956, Nov., pp.45) Effects of pollution on streams and legal requirements are summarized.

Hard char from brown coal: pilot carbonization plant at Morwell R. S. Higgins and G. L. Kennedy (*Chem. Eng. Min. Rev.*, 1959, **51,** April 15, 53–61) 'Hard char' is obtained from the Yallourn, Victoria brown coal deposits by drying and briquetting, followed by upgrading by heating to 900°C to remove volatiles. The resulting product, containing about 4% ash, is very high in fixed carbon and can be used in place of hard metallurgical coke (i.e. in cupolas). The pilot plant built at Morwell to explore the commercial possibilities of the material is described, and the results of trials reported and assessed.

The hydro-refining of benzole at the Carling coking plant of the Houillères du Bassin de Lorraine, St. Avold, France W. Fitz (*Coke Gas*, 1959, **21,** Aug., 321–325).

Today's processes for gas purification A. L. Kohl and F. C. Riesenfeld (*Chem. Eng.*, 1959, **66,** June 15, 127–178) The report is based on a book *Gas Purification* to be published by McGraw–Hill. Processes described are restricted to the removal of gas-phase impurities (119 refs).

AIR POLLUTION AND SMOKE

Atmospheric pollution by iron and steel works (*Iron Coal Trades Rev.*, 1959, **179,** Aug. 21, 99–100) A note on the 1958 report of the Inspector of Alkali etc. works. Sintering and blast-furnace plant, open-hearth installations, and the use of oxygen and the hot-blast cupola are reviewed.

The application of a mechanical collector in combination with an electrostatic precipitator A. B. Walker and J. Phyl (*Blast Fur. Steel Plant*, 1959, **47,** June, 622–624) The development of a high efficiency mechanical collector-electrostatic precipitator combination to meet the need for up to 99% efficiency is described with reference to features of Research–Cottrell designs.

Air pollution control economically through progress in application of catalysis R. J. Ruff (*Ind. Heat.*, 1959, **26,** June, 1187–1196, 1250–1251) The purification of fumes containing hydrocarbon and organic substances from manufacturing operations is considered. The use of platinum-type catalysts is described.

Constant-head aspirator S. R. Howarth (*J. Sci. Inst.*, 1959, **36,** June, 291) A device for sampling air-borne dust is shown.

TEMPERATURE MEASUREMENT AND CONTROL

The measurement of liquid iron temperatures (*Castings*, 1959, **5,** June, 25, 27, 28) A radiation (photocell) pyrometer for foundry use is described.

Measurement, regulation and recording of temperatures: IV. (*Trattamenti Termici*, 1959, **2,** May–June, 22–24) The article describes methods of automatic temperature control with reference to the principles of temperature relay, the photoelectric cell and the electric radio-frequency circuit.

Radiation pyrometer (*Met. Treatment*, 1959, **26,** May, 208) A device with or without a probe for measuring surface temperature, especially in induction hardening, is described.

Development of an experimental gas radiation pyrometer G. W. Duecker and E. L. Woodcock (*WADC* 56–360, *PB* 151031, 1957, July, pp.56) Methods of gas pyrometry applicable to the measurement of combustion temperatures in jet engines are investigated, and the development of an instrument suitable for measuring the extreme temperatures and capable of withstanding engine skin temperatures of 1000°F is considered.

Sleeve guards thermocouple against thermal shock (*Steel*, 1959, **144,** June 22, 89) Silicon nitride is recommended for high temperature use where thermal shock resistance is important. When used for sleeves on suction pyrometers measuring OH air temperatures, four times the life of previous shields has been obtained.—D.L.C.P.

Photometry of the optical pyrometer and its use below 800°C D. R. Lovejoy (*J. Opt. Soc. Amer.*, 1959, **49,** March, 249–253) In this range the accuracy is that of the photometric matching error. Possibilities below 600°C are discussed.

Thermostatic bimetals (*Aciers Fine Spéc.*, 1959, July, 42–47) A review of older and present-day materials and uses.

REFRACTORY MATERIALS

Refractories manufacture at Blaenavon (*Refract. J.*, 1959, **35,** June, 203–206) An illustrated account of a visit to the works.

Refractories usage in steelmaking abroad C. S. Hedley (*Refract. J.*, 1959, **35,** June, 194–198) LD, electric, and OH plant refractories are reviewed for Canada, Australia, Japan, and European countries.

New magnesite brick press T. P. Mann (*Castings*, 1959, **5,** June, 29, 31, 32) A 15½-t press making two 9 × 4½ × 3 in. bricks at a time is described.

Development of bond strength during firing D. H. Houseman and J. White (*Trans. Brit. Ceram. Soc.*, 1959, **58,** May, 231–276) An attempt was made to follow the vitrification process from changes in compressive strength during heating and cooling of test-pieces. In all materials tested the hot strength passed through a maximum as firing temp. increased. On cooling an increase in strength again occurs consistent with the solidification of a liquid phase. Evidence on liquid bonding is weighed and the findings are applied to refractories in service.

Evaluation of quartzite for the manufacture of silica bricks G. S. Minhas and H. V. B. Rao (*NML Tech. J.*, 1959, **1,** May, 32–37) Analyses and properties of the silica and silica bricks are given, and of Indian quartzites.

Use of chrome–magnesite bricks in combination with prefabricated dolomite blocks E. Plettinger and F. Piccinelli (**Atti Notizie*, 1959, (1), 17–19) Dolomite block linings of electric steel furnaces tended to crumble at the doors and water-cooled steel arch supports were too liable to introduce moisture and therefore hydrogen besides the danger of circulating water near the electrodes. Moulded silica bricks were therefore substituted for the supporting arch construction and later chrome–magnesite bricks on magnesite columns which were not attacked by the basic slag. Arch construction and costs are indicated.

Refractory properties of Alabama bauxitic kaolins P. G. Piggott and M. E. Tyrrell (*US Bur. Mines Rep. Invest.*, 5491, 1959, pp.18).

New source of magnesite in Eastern Siberia N. P. Gordeev (*Ogneupory*, 1959, (7), 304–307) The new Tal'sk deposits of considerable proved reserves are equal in quality to the best Sadka magnesite and are moreover situated near the Angara-Pitsk iron ore deposits.

The use of dolomite sands-reserves of metallurgical raw materials V. S. Shevadzutskii (*Ogneupory*, 1959, (7), 307–308) These dolomite sands are found between dolomite deposits in the Elenovsk and Novo-Troisk regions in the Stalin district. Their colour varies from light yellow to black depending on the variety of the matrix. The grains are rounded or half rounded. Analysis shows that the main fraction (0·1–0·25 mm) contains about 19%MgO. Fractions with less than 12%MgO constitute only 6% of the sands. Composition by horizons lying between 100 and 150 metres is very uniform.

Speeding up the operations of the gas chambers of furnaces for firing Dinas bricks P. L. Satanovskii and G. Pevsner (*Ogneupory*, 1959, (8), 344–350) In operating the gas chambers with control of air supply through the gas tubes and through openings to the third cooling chamber, the period of firing is reduced by 17–20%, the productivity of the furnace increased by 20–25% and the coefficient of efficiency raised by 7%. The quality of the fired Dinas objects is not affected. The possibility is thus given of controlling the firing with a much closer gas-air ratio.

Using magnesite bricks with spinel binders in OH furnace roofs Central Laboratory of the Anshan Combine (China) (*Ogneupory*, 1959, (9), 424–429) A process has been worked out for making a high quality roof magnesite brick with spinel binding so that this may practically replace the magnesite–chromite roof brick. The main cause of wear of the magnesite brick is spalling by layers, but the thickness of the layers is smaller than that of the magnesite–chromite bricks.

Refractories of Onotsk magnesite and their use in regenerator checkers of OH furnaces P. N. Dyachkov and I. A. Stepanova (*Ogneupory*, 1959, (9), 403–410) High quality refractories can be made of talc-containing Onotsk magnesite having up to 9%SiO_2 and 1%CaO and about 43%MgO. The production process of periclase-forsterite refractories of Onotsk magnesite does not differ from that of magnesite objects, only the firing must be adjusted and also the method of charging. As regards

chemical composition, the Onotsk magnesite is similar to the periclase-forsterite analysis and as regards physical-chemical indices, these differ only in MgO content of which the refractories contain nearly 80%. Much experimental work however has still to be carried out.

Bricks with high alumina content for checkers of OH furnaces A. R. Makarychev (*Ogneupory*, 1959, (1), 33–38) High-alumina bricks (45–55% Al_2O_3) made from fireclay with addition of commercial alumina proved satisfactory for checkerwork for large furnaces fired with oil fuel supplements. Chrome–alumina bricks with 78–80% Al_2O_3 made from chromium slags are less efficient in service without a water spray.

Air hardening chrome magnesite bonding substances, (mortars) A. A. Pirogov and V. P. Pakina (*Ogneupory*, 1959, (3), 125–129) Based on practical experience the author recommends chrome–magnesite mixtures for blocks and other items of furnace linings, the use of which is advisable on account of the binding properties of the mixes.

Dinas chromite bricks for regenerator checkers of tilting OH furnaces P. N. Slepkanev V. N. Saenko, G. M. Bei, and I. I. Nemets (*Ogneupory*, 1959, (5), 222–224) The erosion of these bricks when used with high phosphorus pig irons begins at the contact surface with the melt. At the same time a small quantity of dinas chromites penetrate into the brick because of the solution of the silica binder. Best results with these bricks are obtained for service below 1350° in checkers.

The role of periclase in forsterite refractories P. P. Budnikov and B. N. Bogomolov (*Ogneupory*, 1959, (6), 263–267) The most reactive constituent of forsterite refractories is periclase, which subjected to the action of iron and aluminium, especially in th presecence of sulphur or alkalis, forms $MgFe_2O_4$ and partly $MgAl_2O_4$ and solid solutions. The large periclase crystals break up meanwhile into small round grains with subsequent spreading out. This is connected with volume changes, the weakening of the structure and the reduction in the physico-chemical properties of the forsterite refractories (heat resistance, strength etc.)

Slags of ferro-alloys used in the manufacture of alumina refractories V. A. Bron and A. A. Bichurina (*Ogneupory*, 1959, (5), 216–221) Slags from the alumino-thermic production of ferro-alloys are a raw material of high alumina content used for refractories for temperatures above 1800°, containing 69–89% Al_2O_3 and considerable amounts of MgO and CaO. Slags with a preponderance of CaO consist of lime-containing 'β-alumina' and those with a predominance of MgO, of alkaline 'β-alumina'. Refractories can be obtained from ferro-chromium and from ferro-chromium alumina slags individually as raw materials containing 66–86% Al_2O_3. Ferro-titanium and nitrided ferro-chromium slags may be used as burden components together with slags from metallic chromium (or ferro-chromium without carbon).

Investigating the influence of the bricks in the ladle lining on the contamination of steel, by means of the ^{45}Ca isotope I. A. Ol'khovskii and M. I. Diesperova (*Ogneupory*, 1959, (6), 258–262) An assessment of the contamination of steel by introducing ^{45}Ca into the refractories cannot be reliably carried out by electrolytic deposition of the non-metallic inclusions because it is impossible to determine the inclusions which are the reaction products of the metal with the refractories containing Ca. Better results may be obtained from an analysis of the rejects cast in refractory linings containing the radioactive isotope.

Examination of some refractory-slag reactions by contraction tests J. F. Hyslop (*Trans. Brit. Ceram. Soc.*, 1959, **58**, June, 329–336, discussion 336–340) Data were obtained for MgO, $2MgO.SiO_2$, $MgO.Fe_2O_3$ and $MgO.Cr_2O_3$ with 8% basic OH slag at 1300, 1400, 1500, 1600, and 1750°C and for basic brick with slag and basic and high-Al_2O_3 brick with cement clinker. Used bricks from roofs, back walls, and uptakes were also sectioned. Mg ferrite and forsterite rapidly lost refractoriness, Mg chromite absorbed SiO_2, Al_2O_3, and MgO, high-SiO_2 in chrome-magnesite giveshigh contraction with slag and high chrome-Fe_2O_3 gives expansion. Al_2O_3 refractories expand in contact with cement.

A note on sluggish silica transformations S. B. Holmquist (*Zeitschrift für Kristallographie*, 1958, **111**, (1), 71–76) Tridymite may not be a stable phase of pure SiO_2 at ordinary pressure.

Some remarks on Metropolitan [French] refractory clays V. Charrin (*Chal. Ind.*, 1949, **40**, Oct., 323–328) A review of localities, with maps.

Influence of rate of heating upon properties of refractory materials F. Savoli and M. Quatrosi (*Calore*, 1959, **30**, Aug., 409–411) An empirical formula is derived, based upon an equation of rate of reaction at variable temp.; the effects of high temp. for brief periods are compared with those of lower temp. for longer periods, and the results for industrial practice are described, supported by two tables of experiments upon four varieties of materials at 1200, 1300, 1400, and 1500°C.—S.H.-S.

Instrumental analysis of refractories W. S. Treffner (*Refractories Inst. Techn. Bull.*, 1959, July, (101), pp.11) Emission spectrographic methods for routine use are described. X-ray spectrographs are included, and the use of statistical methods is noted.

Kaolinite–mullite reaction series. I. A survey of outstanding problems G. W. Brindley and M. Nakahira (*J. Am. Ceram. Soc.*, 1959, **42**, July, 311–314) The problems considered are the nature of metakaolin and the status of γ-alumina in relation to mullite. **II. Metakaolin** (314–318) A structure is suggested. **III. The high-temperature phases** (319–324) Development of a spinel structure and its transformation to mullite is traced and the nature of the intermediate phase is discussed.

Determination of pore size distribution in refractory materials R. Pampuch (*Prace Inst. Hutn.*, 1959, (1), 11017) First the method of measurement and the principle of operation of the SK pyrometer are given. This is followed by considerations of distribution in various materials. It was found that there was a relationship between pores of about 14 μ diameter and slag resistance as well as between pores of about 3 μ diameter and compressive strength.

Suiting the insulation method to the application (*Ind. Heat.*, 1959, **26**, May, 1005–1014) The application of mineral wool blocks to the insulation of a boiler and its equipment is described. Three methods of fixing are described in detail. Strength of the blocks allows them to be used with minimum of support.—D.L.C.P.

Quality control of an order P. Lapoujade and M. P. Guyot (*Centre Doc. Sidér. Circ.*, 1959, **15**, (10), 2123–2129) Quality control of the manufacture of silico-alumina blast-furnace refractories is described.

Research into the sintering of pure oxides with and without the addition of other substances R. Pampuch (*Prace Inst. Hutn.*, 1958, **10**, (6), 333–348) Sintering of narrow grain-size fractions of some 15 oxides was examined on a hot-stage microscope. Investigations were made of the influence of various additions on the sintering of pure BeO. Theoretical concepts are advanced on the sintering process in the solid phase with special reference to pure oxides. The experiments relate mainly to the thermodynamic phenomena occurring in the first stages of the sintering process with particular reference to the initial sintering temperature. It was found that this temperature rises with the decrease in the surface energy of the substance. Experimental data on some of the more refractory oxides show that the most marked reduction in this temperature is effected by the addition of oxides with a low electronegative value for the Me–O bond, i.e. those substances whose structure differs appreciably from the purely ionic, and with a corresponding cationic value. It is also considered that the phenomena of diffusion and vaporization of condensed moisture play a small part in the initial stages. Macroscopic vaporization may occur, but in all probability this is not the result of surface tension.—M.T.

IRON AND STEEL, GENERAL

Report of a journey to the United States C. Crussard and G. Pomey (*Centre Doc. Sidér. Circ.*, 1958, **15**, (11), 2249–2258) Some general impressions obtained during a visit to USA regarding American iron and steelmaking developments, new physical methods of analysis, and research into metal physics are recorded.

An inspection trip diary of the iron and steel industry in the US and Europe. VI C. Asada (*Denki-Seiko*, 1959, **30**, March, 183–196) An account is given of visits to works and technical institutes in Germany, Denmark, Sweden, Norway, and Italy.

New techniques of American steel plants (*Met. Constr. Méc.*, 1959, **91**, June, 435–439) An outline is given of the Strategic Udy process and of the vacuum casting of large forging ingots as practised by Bethlehem Steel.

The possibility of reducing coke consumption in ironmaking P. Epron (*Génie Civil*, 1959, **136**, Oct. 1, 393–396; Oct. 15, 415–417) Consumption for 1958 is given and possible economies by charge preparation, ore beneficiation and other measures are discussed. The use of various other fuels is considered. Injection through blast-furnace tuyeres and the various direct processes are briefly reviewed.

China and her race for steel production B. Crozier (*Steel Rev.*, 1959, July, 8–19) A general article.

Present situation of Japanese steel industry K. Saigo (*Iron Steel Eng.*, 1959, **36**, June, 69–74) Post-war development is described, with production data, and present problems related to shortage of raw materials and export requirements are discussed.

Automation in iron and steel making processes J. E. Oram (*Blast Furn. Steel Plant*, 1959, **47**, July, 716–724) Automation in the sintering, blast-furnace, OH, and soaking pit plants is discussed with reference to the present position and future prospects.

The need for continuous improvement in the qualities of steels and of sections E. Traian (*Metal. Constr. Masini*, 1959, **11**, (5), 374–376) A program for improvements in accordance with the decision of the IInd PMR Congress of November 1958.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

New operational features in Patricia blast furnace at Fairless Works R. H. White, W. O. Smith, and P. E. Hutchings (*Iron Steel Eng.*, 1959, **36**, June, 75–86) Innovations include a status-indicating graphic panel, automatic stove reversing and charging control systems and individual air proportioning controls.

Australia's largest blast furnace (*Australasian Eng.*, 1959, **51**, June 8, 77–78) A brief account of the new furnace at Port Kembla and the other items of the installation.

Running-in a large blast furnace F. F. Ryazanov, P. G. Netrebko, V. L. Pokryshkin, D. S. Yalovoi, L. P. Brusov, and G. B. Rabinovich (*Stal'*, 1959, (9), 770–776) A furnace with a working capacity of 1719 m^3 was blown in in September 1958, and the various difficulties arising from faults in equipment and operation are described and the way in which these were overcome. The coefficient was finally brought to 0·73 and the coke rate to 725 kg/t iron. Materials balances are given.

Experience with self-fluxing sinter at the Steel Company of Canada Ltd J. S. McMahan (*Blast Furn. Steel Plant*, 1959, **47**, July, 695–705, 713) The results of a blast-furnace trial carried out in 1957–8 are reported in detail; the amount of self-fluxing sinter was gradually increased from 60–100%. Details of operating conditions; sinter types and other burden data are given. Pelletizing trials are also dealt with.

Here's how to muffle blast furnace noise (*Steel*, 1959, **144**, June 15, 152) Snort valve silencers filled with spun metallic wool, have been fitted to blast furnaces at Kaiser Steel, to reduce noise to an acceptable level.—A.G.

Research undertaken during 1958 Comité International de Recherches sur le bas Fourneau (*Rev. Univ. Min.*, 1959, **15**, Sept., 710–713) An account of the investigations on the low shaft blast furnace undertaken during

1958 at Ougrée, and based on a report issued by IRSIA.

Introduction of reducing gases into the hearth of a blast furnace M. A. Shapovalov (*Iron Coal Trades Rev.*, 1959, **179**, Sept. 18, 329–334) Translated from *Stal'*, 1958, (5).

Automation's taking over in the blast furnace J. E. Oram (*Steel*, 1959, **144**, May 11, 152–155) The possibility of automatic process control of the blast furnace is considered, involving the intermediate steps of automatic charging, programming, computation of charge composition and data logging.—A.G.

Automation of blast furnace production V. Yu Kaganov (*Metallurg*, 1959, (5), 7–11) Ferrous metallurgy in the Soviet Union is concentrated mainly in large units of high productivity where about 90% of all the pig iron is smelted in mechanized furnaces fitted with a number of automatic control devices chiefly as regards charging. Lately control schemes have been introduced which are regulated by the course of the process itself so that when normal production is disturbed, the respective parameters of the separate sections are automatically adjusted. A scheme of complex automatic control of a blast-furnace is discussed.

Increasing labour productivity in the raw materials storage yard of the blast furnace plant K. M. Kinyapin and L. Ya. Shparber (*Metallurg*, 1959, (4), 8) The automation of the skip hoist in 1949–50 at the MMK, and conveyors, have set free all operatives in these sections. Since 1954 further automation has reduced the number of operatives, for example, two per shift for the cleaning of the skip yards etc.

A study of the movement of materials and the mixing of the metal in the blast furnace by means of radioactive isotopes I. G. Polovchenko (*Stal'*, 1959, (9), 782–784) Counter tubes were used designed to simulate more closely in size and density the materials whose progress it was desired to trace. Diffusion effects are considered in assessing the findings. Three casts were studied, retention of radioactive material appeared to obscure the processes in the second and third.

The permissible amounts and use of radioactive cobalt for detecting blast-furnace lining wear A. Metcalf (*JISI*, 1960, **194**, March, 360–363) [This issue].

Blast furnace operating with fluxed sinter sorted by size S. K. Trokalo, N. M. Yakubtsiner, and A. B. Shur (*Metallurg*, 1959, (4), 3–7) In order not to reduce the intensity of the smelting process in large blast-furnaces, gas permeability may be increased by reducing the relative amount of slag, by increasing the physical condition of the raw materials and of the fuel. From operations at home and abroad with fluxed sinters it follows that for large furnaces the fluxed sinter should be separated according to coarseness before charging and that the operations can be speeded up by automatic control, weighing, and proportioning.

Application of SR-4 resistance wire gauges to the centring of blast furnace bells H. D. Wren, and N. Kurfiss (*Blast Fur. Steel Plant*, 1959, **47**, June, 608–612, 645) The use of SR-4 resistance wire strain gauges for centring the blast furnace bell is described in detail.

Development of blast furnace technique N. I. Krasavtsev (*Metallurg*, 1959, (9), 4–6) Pig iron production is to rise to 70 mil. tons by 1965. To attain this figure improvements in the preparation of ore are intended which will give concentrates with an iron content of over 60%. The burden materials will be sorted according to coarseness, into 15–35 mm and 35–50 mm groups. Finer fractions to be nodulized. Sintered burdens to form up to 90% of the entire charge. Mechanization and automation of production will be vastly increased.

Automatic control of composition and temperature of peripheral gas and control of the operations of the blast furnace Z. I. Nekrasov and Ya. M. Obodan (*Metallurg*, 1959, (2), 7–10) The article describes a device designed by the Institute of Ferrous Metallurgy of the Academy of Sciences which enables constant sampling and fine filtering of samples of peripheral blast-furnace gas to be carried out and also provides for automatic analysis and recording of the chemical composition of the gas. This equipment has been used for a long time at the Dzerzhinsk and Petrovsk plants and others. Experience has shown that the higher the CO_2 content of the peripheral gas and the simultaneous increase in the CO_2 content of the gas, the better the productivity and the coke consumption of the furnace. The CO_2 content must not be less than 7–7·5%. Only when a large amount of fines are used in the burden can the CO_2 content of the peripheral gas be less. A very low CO_2 content at the periphery can be the result of incorrect distribution of the charge at the top, a marked destruction of the lining or blocking up of the centre zone of the hearth. When the gas composition is not uniform due to unstable furnace working, the following will help: (1) a temporary change in the system of charging (coke first and raise the charging level by 0·25–0·5 m); (2) with long and hot working of the furnace increase the ore charge; (3) change the blast conditions; (4) vary slag basicity; (5) improve coke screening.—R.S.

Temperature of pig iron and slag in the production of conversion iron at Magnitogorsk I. S. Kulikov, G. A. Sokolov, I. Gul'tyai, V. M. Zudin, N. N. Babarykin, and A. L. Salatonov (*Metallurg*, 1959, (7), 4) The difference in temperature between the slag and the iron at tapping is to some extent an index of smooth furnace working. Variation in metal temperature during tapping is caused by the temperature distribution in the hearth. Since the temperature of the iron at tuyere level is irregularly distributed, it may be assumed that horizontal metal flow is rare in the hearth. The Si content of the iron depends on the temperature of iron and slag but no great variations in silicon content were observed.—R.S.

Pig iron production using ferro-coke Pak Sin Nok (*Metallurg*, 1959, (6), 5–7) In 1955, tests were carried out on producing pig iron using ferro-coke in a 250-ft³ blast-furnace. A 30% reduction in coke consumption per ton of pig iron was effected, using a ferro-coke blend of 50% ore concentrate and 50% coal. The daily output of the furnace increased by 45–50%. In addition, the gas permeability of the burden and the gas distribution greatly improved. As the ore concentrate content in a charge of ferro-coke increased, conditions for the reduction of silicon improved. Industrial tests were carried out in 1958 at the Kvanke plant. At the beginning of 1958, the manufacture of ferro-coke was started and ferro-coke with 10% ore concentrate and 90% coal was used in one of the blast furnaces. The Fe 56·88, SiO_2 20·04, Al_2O_3 1·19, CaO 0·59, MgO 0·30, P_2O_5 0·15, S 0·055%. The coal analysed: ash 10·69, volatile matter 25·52, non-volatile carbon 62·12, moisture 0·69 total S 0·64%. Lump ore of the following composition was also used in the furnace: Fe 46·93, SiO_2 15·94, Al_2O_3 0·54, CaO 2·21, MgO 1·70, P_2O_5 0·136, S 0·032%. When the furnace was operated on ferro-coke, stack wall temperatures and the temperature of the peripheral gases decreased from 500 to 450–470°C and the descent of the burden was accelerated. To reduce the silicon and sulphur content, slags of high basicity were required.—R.S.

Determination of the practical limits of desulphurisation in the blast furnace H. Canguilhem and V. Rioseco (*Problemas de la Industria Siderurgica, y de Transformacion de Hierro y Acero en America Latina*, 1957, **2**, 4–12) A method is described of calculating the sulphur content of the iron in terms of the burden and slag compositions, as applied at the blast-furnace plant of the Compania de Acero del Pacifico S.A., of Talcahuano, Chile. **Influence of manganese on the desulphurisation of pig iron** R. A. Hacking and C. E. A. Shanahan (13–18) The general theory of desulphurization by slags is discussed, followed by an outline of conditions in British practice and a description of the mechanism of desulphurization in the ladle and mixer, with reference to the influence of Mn on the reactions taking place. **Desulphurisation of pig iron by means of sodium carbonate** P. Coheur (18–28) The theory and practice of various methods of desulphurizing with Na_2CO_3 are described and discussed, and economic aspects considered.

Desulphurisation of pig iron by means of lime B. Kalling and S. Eketorp (34–39) The metallurgy and economics of the process of desulphurization of pig iron by lime in a rotary furnace are discussed, with numerical examples. **Recent progress in the desulphurisation of pig iron by means of lime** B. Trentini, L. Wal, and M. Allard (39–49) A description of the IRSID process of desulphurization by the injection of pulverized lime. **The dephosphorization and desulphurization of pig iron and steel by means of synthetic slag** R. Perrin (28–34) Technical and economic aspects of the removal of P, S, and Si by means of synthetic slags are discussed. **Production of pig iron in electric furnaces** K. Sandvold (49–53) The development of the Tysland-Hole type of electric smelting furnace is outlined, and the recent construction in Norway at Mo-i-Rana is described. **The production of pig iron and steel, by the electric process** H. Walde and B. Marincek (53–58) The methods of producing iron in the low-shaft electric furnace and of steel in the electric arc furnace are considered, and compared with the conventional blast-furnace and open-hearth and converter techniques. **The low-shaft electric furnace at Ougrée** International Steering Committee (58–60) The results of trials in the low-shaft electric furnace at Ougrée, Belgium, are outlined and discussed.

Double walled loading skip I. L. Kordabnev (*Metallurg*, 1959, (3), 7–9) A drawing and description are given for a double walled skip, which, it is claimed, has a service life increased by 1–1·5 years and may be used for stacks in which the gas pressures reach 1·5 atm.

Automatic control of rotary distributor V. P. Pevtsov (*Metallurg*, 1959, (10), 7–9) The operation of an automatically controlled rotary distributor at the Dzerzhinsk plant is described. It was found that the temperature of the peripheral gases gives a reliable impulse for the automatic control of the gas stream from the top.—R.S.

Continuous automatic proportioning hoppers A. P. Mal'kov (*Metallurg*, 1959, (6), 8–10) A description with diagrams of the standard automatic hopper LDA-100 T for continuous operation.

On the electrical equipment of a skip hoist for the No.2 blast furnace, Kokura Steel Works T. Isahaya, K. Nakano, and Y. Hirata (*Sumi. Met.*, 1959, **11**, Jan., 3–13) The reconstructed furnace has a new method of skip hoist control, operated fully automatically by schedule timers. The drivers have ac motors with reactor control equipment; the torque-speed characteristics are similar to those of Ward-Leonard controls, but capital costs are lower and reliability is better.—K.E.J.

Automatic control of the chemical composition and temperature of the gases across the diameter of the furnace Z. I. Nekrasov and Ya. M. Obodan (*Metallurg*, 1959, (3), 5–7) The installation consists of two consoles (one long and one short) for the automatic self-recording gas analyser with a self registering electronic potentiometer, of switches for the gas exhaust points, thermocouples gas ducts and electrical conductors. The entire assembly is fixed in the shaft across its diameter and controls automatically the composition and temperature of the gases from the periphery to the centre.

Rational sequence of switching blast furnace stoves I. A. Ivanov (*Metallurg*, 1959, (10), 9) The correct order in which stoves should go on blast so as to effect uniform heating and cooling of the blast main is discussed.—R.S.

New design of hot blast valve M. A. Tylkin, V. I. Sivak, I. F. Parfent'ev, and M. A. Kropp (*Metallurg*, 1959, (10), 10–11) The characteristic defects of hot blast valves with cast bronze rings and bronze slides are mentioned. A new welded valve cast from furodite (27 to 29%Cr–5%Al alloy) with an internally machined surface is described. Fireclay rings are used.

Reducing sulphur content of pig iron P. M. Matveev (*Metallurg*, 1959, (3), 10) If during the lengthy operation with highly basic slags the walls of the furnace are covered with lime incrustations and the working volume containing the metal decreases in consequence, the desulphurization reaction departs from equi-

librium condition and the sulphur content increases. The hearth must be washed with Bessemer acid steel slags or other acid materials to wash away the lime deposit on the hearth walls.

Reducing the sulphur content in pig iron G. A. Volovik (*Metallurg*, 1959, (6), 3–5) A review of the position in the Soviet Union pointing out the need for further study of acid slags in blast furnace production with subsequent desulphurization of the pig iron.

Low shaft furnace pilot plant (*NML Techn. J.*, 1959, **1**, May, 11–14) An account of the Jamshedpur experimental installation and the objects for its construction.

Determination of the profile of low-shaft furnaces W. Koch (*Neue Hütte*, 1959, **4**, July, 398–403) The underlying principles and the recommended dimensions of the main parameters of the low shaft furnace are enumerated, including charge height, hearth area and volume, and shaft and throat area (10 refs).

Metal savings in the transport of liquid pig iron S. Popa (*Metal. Constr. Masini*, 1959, **11**, (5), 393–397) A study of the conditions under which a liquid metal transport container should operate to effect the greatest savings in metal. The conclusions from tests carried out over considerable periods are put forward. They are concerned mainly with the optimum period of service.

Investigation of the relationship of specific coke consumption to melting rate in the blast furnace (experience of Communist China) A. Bichler (*Hutn. Listy*, 1959, **14**, (6), 476–478) The first of a series of reports dealing with improvements in furnace practice achieved in China.

Natural gas can improve blast furnace operations T. F. Baily (*Iron Age*, 1959, **184**, July 16, 104–105) The effects of injecting natural gas through the tuyeres are discussed. It is considered that, by this means, coke could be saved with a consequent reduction in slag volume and an increase in capacity.—A.G.

Automatic tuyere control improves blast furnace operation (*Iron Steel Eng.*, 1959, **36**, May, 150) A brief account, illustrated by diagrams, is given of a system introduced by B–I–F–Industries Inc. of Providence, RI, by which the balance of blast air is maintained by a tuyere control arrangement in which the flow of air into the furnace is kept uniform.

Iron cement reduces furnace downtime (*Iron Steel Eng.*, 1959, **36**, May, 153) Time was saved in blast-furnace repairs by packing warped parts with iron cement, used as a filler and grouting material.

Removing sulphur and silicon from hot metal (*Met. Prog.*, 1959, **75**, May, 91–94) Details are given of trials on the rotary reactor developed by Diamond Alkali Co. for removing S or Si, or both elements, by pouring hot blast-furnace iron into a rapidly rotating drum, and treating with suitable additions.

Analysis of furnace operations with oxygen fed to the flame M. M. Kotrovskii, M. S. Shklyar, V. G. Paramonov, and V. I. Gol'tsman (*Metallurg*, 1959, (5), 21–23) Experimental work with OH furnaces has shown satisfactory results in the use of oxygen. Oxygen at the rate of 2000 m³/hour should be supplied through tuyeres during charging and heating up and through injectors (1200 m³/h) during the charging of the pig iron, melting and refining periods.

Measuring the level of the charge in the stack by ultrasonics Yu. Ya. Treister (*Metallurg*, 1959, (5), 11–13) Block diagrams and descriptions of an ultrasonic vibrator are given together with indicator, automatic recorder, amplifier, transducer etc. The vibrator and transducer are placed in the mouth of the stack. The remainder of the apparatus is assembled in a suitable observation post. The vibrations reflected by the top level of the charge in the stack pass to the transducer, are amplified and led to a recorder.

Increasing the strength of the air duct branches for the hot blast I. A. Ivanov (*Metallurg*, 1959, (4), 7) A description is given of the arrangement at the MMK works of the air mixing ducts cut into the hot air ducts between the first air heater and the furnace to secure an improved mixing of air.

Mechanism and kinetics of reduction of iron oxides E. Iwanciw (*Arch. Hutn.*, 1959, **4**, (2), 133–159) Pure sintered Fe_2O_3 and natural magnetite were reduced with $CO+CO_2$ mixtures in presence of C. Reduction of Fe_2O_3 and Fe_3O_4 is accelerated by rise of temp. and the curve of degree of reduction/time is parabolic with deviations at 1000° and 1100°C. The energy of activation for Fe_2O_3 is 34·3 kcal/mol and for magnetite 38·1 kcal/mol. Results of porosity and cracking are considered and a mechanism is suggested (20 refs).

Automatic throttling gas valve 1100 mm in diameter V. S. Patrikeev (*Stal'*, 1959, (9), 784–786) A valve for the stove of a blast-furnace is described. The valve is driven by a double worm gear and is electrically controlled.

Hydro-pneumatic cleaning of water pipes I. M. Ushakov (*Stal'*, 1959, (9), 862–864) A method of clearing deposits due to Zn in the ores used in Kuznetsk blast furnaces from the gas purification train is described.

Economic conditions and prospects of Krupp–Renn processing of iron ores J. Mach (*Czech. Heavy Ind.*, 1959, (8), 2–6) Features of the process are discussed and possible advanced designs are considered.

H-iron N. Wood (*West. Metalw.*, 1959, **17**, July, 37–39) A discussion of the process as worked by Bethlehem Steel at Seattle.

PROPERTIES, TREATMENT, AND USE OF SLAGS

Theory of equilibrium of molten steel slag. I. On the equilibrium between the molten FeO–Fe_2O_3–CaO SiO_2–O_2 system and an oxygen atmosphere A. Yoshida (*Nippon Kinzoku*, 1958, **22**, Oct., 548–552) The molten slag is described in terms of two lattices containing FeO, CaO, and SiO_2, and the positions of the positive ions are established. The variation of potential energy between neighbouring ions and slag composition is described. The equilibrium between molten slag and oxygen is expressed by free-energy equations.—K.E.J.

Production of alumina from blast furnace slags L. P. Khodak and A. I. Ivanov (*Trudy Inst. Met.*, 1958, (2), 253–256) Because there are no known large local bauxite deposits in Eastern Siberia where large aluminium plants are shortly to be erected the utilization of alumina-containing slags is a problem of great importance. The experiments described deal with the utilization of the Magnitogorsk Combine slags containing 15–17% the Novo-Tagilsk 17–19%, and the Orsko–Khalilovsk 26–30% Al_2O_3. The granulation of the slags costs 10–12 rbls so that the granulation per ton of Al_2O_3 varies between 45 and 75 rbls. The high SiO_2 content in blast-furnace slags causes the formation of ternary compounds with Al_2O_3 and CaO (hellandite and anorthite), which cannot in practice be leached out in soda solutions. Procedures for the different slags are explained.

Electrochemistry of molten slags O. A. Esin (*Trudy Inst. Met.*, 1958, (2), 41–45) A summary of the knowledge, with references, regarding the confirmation of Faraday's law of the electrolysis of Fe, Mn, P, and blast-furnace slags, both cathodic and anodic, the transport number and electrical conductivity of the Ca and Fe in blast-furnace slags, the e.m.f., the structure of liquid slags, electrode polarization, etc.

Influence of the oxide components of molten slag on the internal tension between the iron and the oxide phases S. I. Popel' (*Zhurn. Fiz. Khim.*, 1958, **32**, (10), 2398–2402) Tension at the iron-oxide phase boundary depends on the slag inclusions in the steel. To investigate the influence of the individual oxides, experiments were carried out with chemically pure CaO, SiO_2, Al_2O_3, and FeO at 1580°C. Tension was found to be high (1060–1295 erg/cm²) for the first three, and to increase slightly with the replacement of SiO_2 by the other two oxides. Regarding iron oxide however, tension decreases sharply because of the absorption of the similar particles of iron and oxygen). This reduces the asymmetry in the field of force at the interphase boundary.

Phase equilibria in the system CaO–iron oxide–SiO_2 in air B. Phillips and A. Muan (*J. Am. Ceram. Soc.*, 1959, **42**, Sept., 413–423) Quenching technique studies were made and diagrams showing stability relations among the various phases are constructed making use also of published results.

DIRECT PROCESSES

Republic scores in direct reduction (*Steel*, 1959, **144**, June 22, 44–45) A new direct reduction process developed by Republic Steel Corp. is described. After successful laboratory trials, pilot plant tests are planned. Iron ore is highly purified and reduced to Fe powder; this is funnelled between four rolls, where it is compressed into semi-solid strip. This passes through a furnace (where it is heated to 2200°F in a reducing atmosphere). The strip is then reduced to correct thickness and density. Hot coils are of the same quantity as those conventionally made.—D.L.C.P.

Instant steel: Will it revolutionize metal-working? J. Joseph (*Western Metalw.*, 1959, **17**, June, 37–40) The Madrigal direct steel-making process is described. Iron ore, fluxes, alloying compounds, and a secret reducing agent are mixed and heated to about 3000°F; after about 30 min the finished steel is ready. The process has been tried privately for several years and patents have been applied for. The equipment required is simple so that local users and underdeveloped countries could use the method. Costs may be nearly half those for producing steel conventionally. The product, reported to be excellent, is still being extensively tested. Commercial or alloy grades can be made according to the ingredients used.

Results obtained in producing steel in the rotary furnace 'B.V.H. Lincar' with basic lining and fired by naphtha A. Bargone and E. A. Hanne (*Met. Ital.*, 1959, **51**, March, 65–68) Details of furnace construction, operational data, consumption; and costs are given for the production of about 2000 t of steel (400 taps). The tests carried out and results obtained in the same furnace in producing iron from iron ore are described.

Industrial rotating furnace A. A. Garkusha and A. Z. Ryzhavskaya (*Metallurg*, 1959, (6), 20–22) A detailed description with diagram of the 80 t rotary furnace; also construction details.

PRODUCTION OF STEEL

Rural steelmaking in China B. Boni (*Met. Ital.*, 1959, **51**, March, 74–75) This article describes the regional development of iron and steelmaking in China and the methods which are now being used to achieve a great expansion of the industry by constructing small primitive furnaces on a country-wide scale and harnessing local unskilled labour forces for this purpose. It is emphasized that the drastic diversion of labour and resources to heavy industry is causing much disruption of the economy.

How much oxygen does a steel mill use? (*Steel*, 1959, **144**, June 1, 119–121) The use of O_2 converters and O_2 jets in OH roofs has increased O_2 consumption in America to 390 ft³/t of ingots produced. Further expansion is predicted.—A.G.

The optimum conditions of hot metal additions, produced in the M.B.C. cupola, to the open-hearth furnace charge S. T. Jazwinski (*Mét. Constr. Mécan.*, 1959, 91, Sept., 631, 633, 635, 637, 639) After a general discussion of factors influencing the melting down and refining of an OH charge, the author describes a series of melting trials carried out at the works of Pheonix Iron and Steel Co., using various proportions of hot metal from the M.B.C. cupola. It was shown that, for a given furnace, optimum results were obtainable using about 40% of hot metal.

Automation of open hearth expected to gain headway J. E. Oram (*Steel*, 1959, **144**, June 1, 100–102) The first step towards automatic furnace control is considered to be comprehensive data logging to establish process correlations. The advantages of automatic charge control are cited.—A.G.

Automatic controls beef up steel output, cut operating costs (*Western Metalw.*, 1959, **17**, May, 47) Pre-set controls enable the correct fuel-air ratio and flame characteristics to be

maintained using oil, gas, or mixtures of the two as fuel. Maximum heat input is also controlled to prevent overheating and damage to refractories.—A.G.

The Warsaw Steelworks B. Baranski (*Brit. Steel*, 1959, **25**, July, 246–247) A brief illustrated account.

The Warsaw Iron and Steel Works B. Baranski (*Prz. Tech.*, 1959, **80**, (5), 5–7) The steelworks is located at Miocine near Warsaw, primarily to supply special steels to the industrial works in the neighbourhood, and also to tap the Wisla river as a source of water supply. The labour force is planned at 3600 for 1958–60, of which 2500 would be fully qualified iron and steel workers. Capital expenditure to the end of 1958 was 1280 million zloty. Production is planned to start as follows: end of 1958, steelworks with two 250-t electric furnaces; 1959, forging and press shops, 70-t OH furnace with a coke-oven gas plant; 1960, two additional 70-t OH furnaces, a blooming mill and an extrusion plant; 1961, a heavy rolling mill and 1962, two small section mills and a medium section mill. Production at the iron works had already started some time before production at the steelworks. There will also be a steel casting section with a 5-t cupola furnace and a 430-kg induction furnace. The forge shop will have 7×0·3–5-t hammers and the press shop a 1250-t and an 3000-t press. Oxygen enrichment of the cupola furnace blast is used at the rate of 5·12 m³/t; installed plant delivers O_2 at 100 m³/h, and it is intended to increase this by two further plants, each of capacity 800 m³/h. Ingots are to be vacuum cast. It is planned to produce 1200 rolling mill rolls per annum for cold rolling and to harden them by induction heating at medium frequencies to a depth of about 25–30 mm only. A fully automatic quantometer analysis device is being installed, which can determine the metallic elements in steel with accuracy and speed.—M.T.

Making the best use of our raw materials D. J. O. Brandt (*Iron Coal Trades Rev.*, 1959, **178**, June 5, 1301–1305) A comparison of British and German OH practice suggests to the author that a balanced industry using the improved converter techniques is necessary to maintain competitive conditions.

The goal of the all-basic open hearth steel furnace achieved (*Blast Furn. Steel Plant*, 1959, **47**, June, 617–618, 651) The development of the sprung arch basic open hearth furnace roof is described, the main features of the design being indicated.

Direct oxidation of the open hearth bath with an oxygen-water mixture G. S. Sel'kin, K. M. Trubetskov, E. A. Grekov, N. P. Zadalya, A. O. Voitov, and A. A. Mitrofanov (*Kislorod*, 1958, (6), 3–7) In the production of low carbon steel, the lancing of the bath with an oxygen-water mixture during melt-down and refining increases furnace productivity by about 7% while reducing the fuel rate by about the same amount, when compared with oxygen lancing during the refining period. No increase in oxygen usage per heat is required. The best time for commencing the oxygen-water lancing is 80 min after start of the addition of hot metal. Lancing must cease when the carbon is 0·02% higher than prior to deoxidation. Oxygen-water mixtures are effective in reducing the amount of flue dust. The possibility of using oxygen-water lancing to produce killed steels and grades sensitive to flaking is being studied.—R.S.

Improving the life of door arches L. A. Malakhovskii and E. N. Leve (*Metallurg*, 1959, (10), 20) Fireclay was replaced with a ramming mass of air-hardening reinforced chrome-magnesite concrete patented in the USSR. A chrome-magnesite mixture was used consisting of 60% chrome ore and 40% magnesite powder. This material was produced at the K. Marx refractories plant. The mixture was moistened with a solution of sulphite waste liquor with a density of 1·2 to 1·25 g/ml, to a moisture content of 3·2–3·5%. This mixture analysed SiO_2 1·4, $Al_2O_3+TiO_2$ 13·42, Fe_2O_3 11·58, Cr_2O_3 25·0, CaO 1·48, and MgO 44·25%. Granulometry was 18·1% of over 3 mm, 18·8% of 3 to 1 mm, 18·6% of 1 to 0·4%, 38·7% or 0·4–0·06 mm, 5·8% of less than 0·06 mm and 3·6% ignition losses. The method of applying this material in the form of door arches is described. The life of these rammed reinforced air-hardening chrome-magnesite concrete door arches was 25 to 33 days, which was 5 to 7 times as long as the life of fireclay.—R.S.

New melting shop of Brymbo 'Oxygen-electric' steelmaking process (*Iron Coal Trades Rev.*, 1959, **178**, May 1, 1021–1030) The pre-refining process, its inception and operation, are discussed and illustrated. A general history of the works is given. The equipment for the production and handling of oxygen is described.

Direct reduction of iron ore in Norway. The Mo i Rana works (*J. Four Elect.*, 1959, **64**, (1), 35–37) The layout and operation of the steel-making and rolling plants at Mo i Rana are described and illustrated.

Technological progress in the steel industry [of America] (*Engineer*, 1959, **207**, May 8, 746–747) A review of improvements in blast-furnace and OH practice and of a newer direct reduction processes which are surveyed.

The role of high-purity oxygen in metallurgical processes H. B. Emerick (*Blast Furn. Steel Plant*, 1959, **47**, May, 463–477) A description is given of the main metallurgical application of high-purity tonnage O_2 in iron and steelmaking practice. The main influences in the development of the use of O_2 are discussed (26 refs).

Making steel by the Stora-Kaldo process (*Blast Furn. Steel Plant*, 1959, **47**, May, 490–492) The plant operated at Domnarvet is described briefly.

Semi-technical 15-ton rotary steelmaking furnace S. V. Makaev, D. F. Nagovitsyn, S. A. Krasovskii, and A. A. Lebedev (*Stal'*, 1959, (8), 689–694) An O_2-blown rotary furnace with basic lining with two jets, one delivering O_2 into the bath and the other discharging it above to burn the CO evolved is described. The steel produced was equal to OH steel. Operation and composition of metal and gases are also set out.

The evolution of converter processes in iron and steel R. Duchateau (*Rev. Ind. Min.*, 1959, **41**, June, 509–519) The Bessemer and basic Bessemer processes are reviewed with special reference to the last 15 years. Uses of O_2 enrichment, O_2-steam and O_2–CO_2 blowing are noted and then a review of the pure O_2 processes is given.

Bath temperature measurement through the mouth of the convertor J. Galey (*Centre Doc. Sidér. Circ.*, 1958, (5), 1049–1058) The two methods of temperature measurement discussed assume that black-body conditions prevail and that the light emitted by the bath is not absorbed by the flame at the mouth of the converter. A wavelength of 6500Å is advocated and the photo-current is measured in terms of voltage. Recording can be effected in terms of time but the author points out the advantages to be gained by recording in terms of the volume of oxygen blown.—R.P.

Progress in the manufacture of converter steel J. Massinon (*ATB Métallurgie*, 1956, **1**, (1), 23–30) A general outline of modifications of the basic Bessemer process, including oxygen enrichment, changes in converter design, and the use of pre-refining is given, and reference is made to the LD process.

The production of various types of steel in basic converters using the oxygen lance S. I. Lifshits (*Hutnik*, 1959, **9**, (5), 145–148) A number of steels, e.g. for crane rails and tubes produced by the LD method, were found to compare favourably with similar rimming and killed steels made in the OH furnace. The technology is described, and the need for further researches on desulphurization and carbon-content control in the converter is discussed.

Injection of powdered materials into the converter blast D. Trentini, P. Vayssière, R. Alleyrac, and J. Legrandjacques (*Rev. Mét.*, 1959, **56**, June, 13–22) An account is given of various aspects of the results of pilot-scale trials carried out by IRSID at the works of the Etablissements de Wendel at Moyeuvre.

Studies of Basic Bessemer converter bottoms W. Köhler, T. Hartmann, and G. Trömel (*Centre Doc. Sidér. Circ.*, 1958, (9), 1745–1769) Factors influencing durability were studied by analysis of vibrating plate movements, and by examination of dolomite samples taken from the converter-bottom. A small degree of porosity was found to be desirable and the state of the lining-base junction to be important. The rapid and frequent variations in temperature, the type of steel processed, and, above 1620°C, the amount of iron oxides and basicity of slag, all affect the durability.

New method of vibrating converter bottoms E. Glaesener (*Centre Doc. Sidér Circ.*, 1958, (9), 1771–1789) Structures and weaknesses of new converter bottoms are discussed together with the wear resulting from different methods of vibration during manufacture. The new method, which is completely independent of the vibrating mass, consists of a system of needles running through the bottom in the mould, each needle becoming a vibration centre.—A.M.A.M.

Manufacture of converter bottoms by means of a vibrating plate J. de Hedouville (*Centre Doc. Sidér. Circ.*, 1958, (9), 1791–1795) Two types of vibrating plate are described which permit simplicity and flexibility of installation and operation.—A.M.A.M.

Unfired converter bottoms used in the basic Bessemer steelworks, Seraing R. Schuermans and J. Vanneste (*Centre Doc. Sidér. Circ.*, 1958, (9), 1797–1812) A description of a new method of producing converter bottoms with increased durability is given. The process differs from the usual one in that the bottom is dried at ordinary temperatures for five weeks, is then placed in the converter, and is fired rapidly (5 h) *in situ*. Performance and costs are discussed, and a tentative explanation of longer life is offered.—A.M.A.M.

Manufacture of converter bottoms at Forges de la Providence, Marchienne M. Ledune (*Centre Doc. Sidér. Circ.*, 1958, (9), 1813–1819) Recent developments in processing and size-grading of dolomite are described, and a brief description of the manufacture of converter bottoms is given. The improvements have resulted in a 50% increase in the life of converter bottoms since 1949.—A.M.A.M.

New processes used in firing the joints in basic Bessemer converter bottoms J. Legrandjacques, de Rousiers, and Delong (*Centre Doc. Sidér. Circ.*, 1958, (9), 1821–1826) Methods of firing with air/coal gas, blast-furnace gas/oxygen mixtures, or electrically are briefly described. The advantages over the old method of coke firing are reduction in shut-down time, and a decreased risk of contamination of the first casting. The power consumption per firing in the electrical process is of the order of only 50 kW hours.—A.M.A.M.

Quality of rimmed steel produced in an oxygen-blown converter from high-phosphorus pig iron F. Krumnikl and R. Štrobl (*Hutn. Listy*, 1959, **14**, (6), 493–498) The results of comparative trials are discussed of steels made in an oxygen-blown converter, a basic converter, and an open-hearth furnace.

Contribution to the metallurgy of the basic Bessemer process H. Beck (*Centre Doc. Sidér. Circ.*, 1958, (5), 913–966, from *Technische Mitteilungen RHW*, 1957, Dec., 245–269) Studies on over 300 charges in a basic Bessemer converter have shown that the Si content of the melt should be as low as possible and that the charging temperature has to be above 1220°C. The P content of the melt and the additions influence the final casting temperature. Dephosphorization depends on the temp. of the steel and on the iron content of the slag but not on its silica or lime content. The nitrogen content of the steel depends on the temp. and composition, the type of additions, on the rate of decarburization, and on the blast pressure; the nitrogen content is independent of the volume and time of blowing and of the Mn content of the melt. For low-carbon rimming steels, the final temp. after blowing should be 1615°C (62 refs).—R.P.

New openhearth practice links oxygen, sprung basic roof O. Pearson (*Iron Age*, 1959, **183**, May 7, 98–100) A proposed design for a 380-t furnace with 1400 ft² hearth area is shown with oxygen roof lances for decarburization. The basic roof design is illustrated. Data on the initial campaign are given.

Control of flame direction in a producer-gas-fired furnace L. Septier, C. Cohen de Lara, S. Terrat, R. Bovios, and M. Fauve (*Centre Doc. Sidér. Circ.*, 1958, (9), 1905–1917) A simple and practical method of controlling flame direction, tried both on pilot and full-scale plants, is described. Effects of varying the position, direction, and pressure of the gas-jet were studied. Correct flame direction was found to reduce consumption of coal per ton of steel by 10%, and to allow the replacement of basic roofs with silica.—A. M. A. M.

Tests on new constructions of separating walls of blind spaces Poulain (*Centre Doc. Sidér. Circ.*, 1958, (5), 1073–1077) The two classical types of separating walls of OH furnaces are examined, i.e. walls with an air space and simple walls. Tests on brickwork with crossed joints and with enclosed air are described. Experiments are in progress in order to find the best possible method of construction.—R. P.

Production of steel in furnaces fired with solid fuel Lu Chun-u, Chin Fu-sen, E Min-chou, U En-ling, and A. S. Burenko (*Stal'*, 1959, (9), 802–804) A description of the Chinese 1·5-t solid-fuel-fired OH non-reversing furnaces with recuperators.

A sliding water-cooled spring-loaded seal for tilting furnaces E. R. Katsman, D. K. Kharlamov, P. N. Slepkanev, and V. S. Filanovskii (*Stal'*, 1959, (9), 804–805) A device to seal the gap between the parts and the moving body of a tilting OH furnace is described. The seal is essentially a steel tube of square section.

New refining plant. Completion of £2 m. development project at Brymbo (*Iron Steel*, 1959, **32**, June, 327–331) An illustrated account.

The L.D. process and the open hearth H. P. Weitzer (*Met. Ital.*, 1959, **51**, July, 297–299) This letter is written to refute a statement that with the OH furnace a higher rate of production can be obtained than by using the L.D. process. The writer cites examples of higher production obtainable by the L.D. process and summarizes its other technical and economic advantages.

The use of radioactive isotopes in studying the kinetics of scrap melting and slag formation in the scrap-ore process A. I. Osipov, L. A. Shvartsman, V. I. Alekseev, V. F. Surov, M. L. Sazonov, M. T. Bulskii, S. A. Telesov, A. M. Skrebtsov, A. M. Ofengenden, L. G. Goldshtein, and F. F. Sviridenko (*Paper presented at Conf. on Peaceful Uses of Atomic Energy*, [1959], pp.5) Applications of the isotope dilution method are described. The absolute weight of slag formed is also determined. Equilibrium expressions are derived and evaluated giving a method of comparison for different furnaces and also the time rate of oxidation of impurities. Data are shown graphically.

A simulation of melting shop operations R. Neate and W. J. Dacey (*Computer J.*, 1959, **2**, July, 59–66, discussion 66–67) A model set up for the melting shop of an integrated steelworks is described, using a Pegasus computer.

Combined method of fettling the new O.H. furnaces I. A. Bedrik (*Metallurg*, 1959, (5), 45) The new 85–90-t OH furnaces at the Alapaevsk Metallurgical works are fitted with chrome-magnesite roofs. The furnaces are heated by generator gas with oil fuel. Fettling of the hearth begins at the maximum temperature of the furnace. The roof temperature should then reach 1640–1690° and the checkers not less than 1180°. Before application of the first layer, the bottom of the hearth and the banks are slagged over with rimming steel slag and the tap opening is closed. The slags are spread evenly over the entire bottom and banks and on the adjoining portions of the front and rear walls. After melting, with compressed air blown through ducts the slag splashes all over. This is repeated three times and after keeping the slag in for 1 to 1·5 h the tap is opened and the furnace drained.

A relay device for reversing the valves of small capacity O.H. furnaces V. M. Studentsov (*Metallurg*, 1959, (5), 26–27) In small furnaces with short charging periods the temperatures in the checkers maintains itself relatively high and the integral relay does not speed up the reversals. In order to extend the time between automatic reversals during charging when the checkers still maintain a high temperature, the integral relay is converted to a motor time relay by means of a separate special relay. The diagrammatic scheme is supplied.

Use of chromium-silicon for making chromium steels V. E. Sokolov, V. I. D'yachkov, A. E. Sokolov, and I. G. Fadeev (*Metallurg*, 1959, (4), 12–14) Cr–Si is applied in two ways. 12–15 Kg/t of steel are added to the boiling metal bath, followed by Fe–Mn and Fe–Cr, or the same amount of Cr–Si is added to a bath, previously deoxidized by Fe–Mn followed by Fe–Cr. The results of these tests on 28 melts are tabulated.

Investigating the strength of the rammed layers in O.H. furnace hearths by means of radioactive isotopes A. M. Skrebtsov and V. A. Kostyuk (*Ogneupory*, 1959, (8), 371–376) A method is described of testing the wear of the rammed layers on the hearth of a tilting furnace by means of ^{32}P. The maximum service life of the fettled layer was attained with a consumption of coking gas of up to 5000 m^3/hour during hot repairs. If the hearth is cooled below 1400° during hot repairs the strength of the layer falls sharply. The wear is less for high carbon steels than for low carbon steels.

The gunning of linings in metallurgical furnaces B. A. Velikin (*Ogneupory*, 1959, (8), 354–360) A method of gunning the linings of metal furnaces has been tested and the gun now forms an essential part of the equipment of furnaces. It extends the duration of the campaigns, so, for example, the campaigns of the anode furnaces at the Noril'sk metallurgical combine have been lengthened three times approximately and those of large furnaces have also been considerably extended. A detailed description of the gun is given, with diagrams.

Regarding the deoxidation and alloying of low-alloy steels B. Kh. Khan (*Metallurg*, 1959, (5), 19–20) Experimental work confirmed that the tapping temperature should be between 1620–1640° at which the hard ferro-alloys dissolve satisfactorily to give a homogeneous composition. There is no difference in quality if deoxidation and alloying is carried out entirely in the ladle instead of with the normal method, but production costs are reduced. The conditions for the operations are detailed.

Changes in the output of the open-hearth furnace and the specific heat consumption during the inter-repair period J. Mikulski and M. Michalowski (*Hutnik*, 1959, **26**, (7–8), 271–276) The authors are concerned with ascertaining the optimum periods for the systematic shutting down of the furnace in respect of the consequent reduction of output and increase of heat consumption. In formulating a numerical concept for this operation, use was made of data gathered during two and a half years in more than ten steel works. A mathematical formulation of the problem is also given.

The use of oxygen for repairing bottoms and increasing hearth life N. L. Lapin (*Metallurg*, 1959, (2), 16–18) The output of the large (81·4 m^2 hearth area) basic furnaces at Nizhne Tagil was increased by cutting down repair times by using oxygen for bottom repairs. When slag and metal accretions on the hearth have been removed by blowing the bottom with oxygen, the hollows are filled up with magnesite powder. This work is carried out during fettling. Oxygen for cleaning the bottoms is fed simultaneously through three tubes (a photograph is shown). During the oxygen blowing of the hearth, roof temperature drops from 1600–1650 to 1350–1400°C. Oxygen blowing of the bottoms lasts 25–30 min. With compressed air this operation lasts from 1½ to 2 h. Thus, the time for bottom cleaning is considerably reduced by using oxygen in heat-resisting tubes.—R. S.

Utilisation of ferro-chromium scrap for melting chromium and chromium nickel steels B. G. Petukhov and N. I. Shirikov (*Metallurg*, 1959, (9), 13–16) High-carbon Fe–Cr scrap was used by the Kuznetsk plant and the Siberian Metallurgical Institute for melting Cr and Cr–Ni steel in all-basic OH furnaces. No difficulties were encountered when Fe–Cr was added during refining. Slags with a high content of Cr_2O_3 at the beginning of the lime boil were sufficiently fluid. The absorption of Cr from the additions varied between 50 and 70%. Steel quality was good and mechanical properties exceeded specifications.—R. S.

Inter-works school for open-hearth furnace bottom repairs G. E. Germaidze and V. G. Pushkov (*Metallurg*, 1959, (2), 13–16) In July 1958, an inter-works school for the repair of open-hearth bottoms was established by the technical management of the Sverdlovsk (Urals) Council of National Economy. Details are given of percentage down time for various works in 1957 and 1958, giving best, worst, and average figures. Description of the methods of bottom repairs are given for three different large iron and steel works in the Urals. Among the recommendations of the inter-works school are: Repairs should be scheduled on a weekly and not on a monthly basis as, on a monthly basis, it is not possible to stop the furnace for repairs at exactly the time when repairs are necessary. Repair times on the schedule should be strictly adhered to. To remove slag and metal from the hearth, compressed air is used at a pressure of not less than 5 atm and, where possible, O_2 is used at a pressure of 6–9 atm, the fuel being either switched off or reduced to a minimum. When oxygen is used, it is fed through three pipes simultaneously. Heat-resisting steel pipes are used.—R. S.

Use of plastic refractory in the hearths of the Siemens-Martin furnaces at Volta Redonda, Brazil E. A. Bastos, C. H. M. Braga, and M. L. Hasek (*Bol. ABM*, 1959, **15**, July, 469–496) A summary of experience with plastic refractory materials in making and repairing hearths of OH furnaces, covering physical characteristics, chemical compositions, behaviour of materials during construction and repairs, and during heating and operation of furnaces, together with detailed technique of building. Satisfactory results, especially economies of time in construction and repair, have caused the adoption of a systematic future use of plastic refractory of MgO.

Study of open-hearth furnace recuperators Denantes (*Centre Doc. Sidér. Circ.*, 1958, **15**, (10), 2111–2116) Factors influencing the thermal efficiency of OH recuperators are discussed, with reference to the example of the satisfactory performance of a Maerz-type furnace in 1949 at Hagondange. A program of investigation of recuperator performance is outlined.

Contribution to the study of the effect of burner jet momentum on open-hearth furnace production R. Kissel (*Centre Doc. Sidér. Circ.*, 1958, **15**, (10), 2081–2110) Research by IRSID is described into the effects of jet momentum on flame emission, and the results obtained in three series of trials are discussed (12 refs).

Thoughts on refining and deoxidation in the open-hearth furnace G. Husson (*Centre Doc. Sidér. Circ.*, 1958, **15**, (10), 2067–2079) The article by H. Schenck on 'Basic considerations in the manufacture of high-quality killed steel' (*Stahl Eisen*, 1957, Oct. 17, 277–300) is discussed and limitations and possible extensions of Schenck's theory are examined. With reference to the ternary diagram $SiO_2+P_2O_5-CaO+MnO+MgO-FeO$, the relationships between slag composition and conditions leading to satisfactory steel deoxidation are studied (14 refs).

Slag washing of stainless steels graduates from pilot stage (*Steel*, 1959, **144**, May 25, 146–149) In the process described, Ti-bearing stainless steel is poured through a special flux to remove inclusions. The hot flux also retards solidification permitting low density contaminants to escape.—A. G.

Computer holds stainless costs D. C. Hilty, R. W. Taylor, and R. H. Gillespie (*Iron Age*, 1959, **184**, July 9, 100–101) A digital computer has been employed to determine the most economical blend of raw materials to produce Type 430 stainless steel. Factors considered were over 30 sources of Cr, costs of O_2 and lime, bath temperature, oxygen blowing rate, etc.—A. G.

Construction and operation of 80-ton electric furnace L. S. Katsevich (*Metallurg*, 1959, (9),

17–19) This article gives full details of the operation and characteristics of the largest arc furnace at present in the USSR which was built in Siberia. Shell diameter is 6300 mm, transformer power is 25000 kW, and electrode diameter is 550 mm. The furnace is three-phase and has three electrodes.—R.S.

Gunned materials increase lining life in electrics R. E. Forsman (*Steel*, 1959, **145,** July 27, 114, 116) Refractory lining repair with water pastes applied between heats is said to improve electric furnace operation. A dry process can also be used.

Oxy-electric steelmaking at Brymbo (*Brit. Steel*, 1959, **25,** June, 198–201) Details of installations and operations are given. A brief history of the site is included.

The Venezuelan steel works M. Gonni (*Iron Steel Eng.*, 1959, **36,** May, 71–93) Details are given of the present and intended capacity of this works, with a description of the plant. Venezuelan hematite deposits will be used, and will be smelted in electric furnaces, because of the quality of coal available and other factors. Steel rolling and tubemaking facilities and ancillary equipment are described.

Automatic charging for electric furnaces with raw materials storage silo R. A. Davidson (*Iron Steel Eng.*, 1959, **36,** July, 157–158, 161–162) A vertical silo-type storage and handling installation is described, providing semi-automatic handling and storage of materials for a ferro-alloy plant with a diverse program, and automatic batch proportioning.

Influence of composition of charge and of final deoxidation on the properties of 30Kh-G8NA steel I. P. Zabaluev (*Stal'*, 1959, (9), 811) A note from Dneprospetsstal'. Steel melted in the basic arc furnace was deoxidized in the furnace with Al and in the ladle with Si–Ca or in the furnace with 0·5 kg/t Al only. The second type of treatment was better according to the step-down test but impact strength was lower.

Electric arc steelmaking using hot metal process (*Metallurgia*, 1959, **59,** June, 265–268) The development of the process at Brymbo is described with an account of pre-refining methods and of arc furnace operation.

An arc furnace control device M. Kiss (*Mérés és Automatika*, 1958, **6,** (4), 114–116; from *Hungarian Technical Abstracts*, 1959, **11,** (2), 52) A control sensitive to both potential and current for steel furnaces and another for a dc Ti melting furnace are referred to.

Refractory concrete as electrical insulation material for electrode coolers in steel melting arc furnaces S. A. Zhikharevich, A. I. Roizen, E. A. Gin'yar, L. A. Kozyreva, A. F. Kablukovskii, and S. D. Skorokhod (*Ogneupory*, 1959, (7), 309–319) Good results were obtained from the use of concrete with a high alumina content and this insulation is now being introduced in all electro-metallurgical plants, especially where oxygen is used. The concrete is generally used together with high alumina-containing fireclay in the proportion of 75–100 kg concrete cement with 400–500 kg fireclay per roof.

Modernization of electric arc furnaces P. M. Rutberg and A. I. Sapko (*Metallurg*, 1959, (4), 21–22) The plan proposes unification and standardization of the different furnaces, 5, 15, 20, 30, and 40 t into one standard size and provides drawings and dimensions to this effect.

The influence of oxygen refining on the metallic charge cost in the manufacture of stainless and heat-resisting steels W. Woznica (*Hutnik*, 1959, **26,** (7–8), 267–271) Oxygen refining used in the manufacture of stainless and heat resisting steels in electric arc furnaces reduces the cost of the metallic charge, since scrap-iron with the excess carbon removed by refining can be used to make up a large portion of the charge. O_2 refining also enables a greater use to be made of scrap in the form of oily shavings. This method is at present in use in the 'Baildon' works.

Production of 38KhMYuA steel for internal combustion engines N. V. Keis, I. Ya. Aizenshtok, A. I. Komissarov, and D. B. Royak (*Stal'*, 1959, (9), 808–811) Melting practice is discussed but even with the best practice 25% discard is necessary owing to segregation, blowholes, and cracks and expecially severe inspection is needed. The nature of these defects is discussed. Forging practice and the defects appearing are also considered. Further work is necessary to improve the technology.

Problems of metallography and the physics of metals, Fourth Symposium B. Ya. Lyubov (*AEC–tr–2924*, (Moscow 1955), 1957, pp.476) (*Problemy Metallovedeniya i Fiziki Metallov.*) **On the Theory and Computations for the introduction of elastic oscillations into molten metals** I. I. Teumin (13–27) A mathematical investigation of sonic and ultrasonic agitation methods. **Effect of low-frequency vibrations in the mould on ingot crystallisation** V. I. Leontyev (28–31) Tests on Zn and on steel A–20 are described. Conditions for fine granulation and elimination of porosity are given. It is recommended that conditions should be used in which the ingot breaks away from the bottom of the mould and is subjected to repeated impacts from the mould bottom.

Device for hydraulic cleaning and dressing of ingot moulds V. F. Zarubin (*Metallurg*, 1959, (9), 19–23) Various types of ingot mould washing devices are described including a cantilever type machine, a hydraulic mould dressing machine using high pressure water for cleaning moulds and combining a device for coating and a new machine which has been designed to operate in the new OH shop at Magnitogorsk. This is a combined installation for hydraulic cleaning and coating.—R.S.

A withdrawal stand for continuous steel casting plant V. A. Karpek, A. S. Kaushanskii, Ya. E. Satanovskii, and A. N. Shabanov (*Stal'*, 1959, (9), 806–807) A device in which roll pressure is applied hydraulically and the self-adjusting chocks are moved by a system of toothed arms is shown. The device takes a wide range of ingot thicknesses without alteration and holds the ingot axis centrally whatever the thickness.

Continuous casting I. M. D. Halliday (*Steel Rev.*, 1959, July, 20–26) A general account of the Barrow process with a world survey table.

Metal processing in Russia A. B. Tesmen (*Met. Prog.*, 1959, **75,** May, 106–108) Russian progress in continuous casting of steel, ultrasonic treatment of solidifying molten ingots, and vacuum rolling is discussed.

Charge material upgraded by rotary scrap shear (*Steel*, 1959, **144,** June 15, 146–147) In the shear described, scrap is cut by a heavy blade attached to a drum rotating once every 5 sec. The cut scrap makes a higher density charge for the OH furnace.—A.G.

FOUNDRY PRACTICE

Casting integrity C. L. Frear (*Foundry*, 1959, **87,** July, 80–85) This is defined as the degree of soundness, strength, ductility, and other properties which exactly meet service requirements. Choice of method for various purposes is discussed.

Design properties of four streamlined cast sections J. B. Caine (*Foundry*, 1959, **87,** July, 91–97) Comparative data for tubular, omega, C, and U-sections are presented.

Specialisation of foundry production V. M. Shestopal (*Lit. Proizv.*, 1959, **9,** (2), 31–33) Specialization should be carried out along the following lines: small precision casting; mass production of castings of special types; production of castings for mass and batch production in the machinery industry; castings for small batches and individual units; and heavy, single castings. Production in these groups is compared with that in the USA and the economic aspects of specialization are discussed. Planned output for 1965, and the directions in which more efficient production are required, are indicated.—M.T.

Measurements of the surface smoothness of castings Z. Sasonowicz (*Prz. Odlew.*, 1959, **9,** (2), 214–218) In the article a number of examples illustrating the meaning of surface smoothness are given. The definition of surface smoothness and certain features of this concept are discussed. Several methods of measuring surface finish are described. In conclusion a new surface smoothness gauge, type GLI, which is specially suitable for foundry work is shown.

Experience in the work of the central foundry laboratory G. I. Kletskin (*Lit. Proizv.*, 1959, **9,** (2), 4–15) Certain special lines of research and development carried out by the central laboratory of the Stankolit Works are described. Eight 8–10-t cupola furnaces are so spaced in two bays that separate recuperators cannot be accommodated; the design of a recuperator built into the top of the furnace is described. Of welded construction, the recuperator has 32 V-shaped seamless 18 Cr–9 Ni tubes 89 mm in dia, wall thickness 5 mm, 550 m mean length, heating surface 145 m². In one half of the recuperator there is a counter-current and in the other co-current of air and cupola gases. Combustion products are preheated to 700–800°C in a tubular furnace before entry into the recuperator. As a result, hot blast enters the cupola furnace at 270–300°C, thereby stepping up output. Such recuperators can be recommended for furnaces of 5-t capacity or over. All the furnaces have now been fitted with water cooling; this is considered economic on high productivity furnaces despite an increase of 4–6% in coke consumption. Refractories presented certain problems, the most troublesome of which was the lining of the passage between the cupola and the forehearth, water cooling was unsatisfactory, and 62% Al_2O_3 brick now gives satisfactory results, while up to 75% Al_2O_3 brick gives even better life, but its cost is very high. The development of the regulation and control equipment of the furnaces has already been given in detail ((9), 1957; N. L. Sobol'). Working with basic slags, irons of 0·02–0·03% S are produced, which are found very suitable for subsequent modification with Mg or blowing in a Bessemer converter. A further section of the article is devoted to mould and core mixtures, binders, and drying and painting. The welding and surfacing of casting defects has also received considerable attention, and an indication is given of the welding method adopted for various types of defects.—M.T.

Specialisation and cooperation between iron foundries in the Leningrad Economic Region E. M. Karlik and G. V. Malakhovskii (*Lit. Proizv.*, 1959, (1), 2–4) 51% of the casting plants in the region produce only up to 1000 t of castings per annum, representing only 7% of the total output. Corresponding figures for up to 3000 t per annum are 76% and 23·8% respectively. Suggestions are made for more extensive mechanization, concentration in larger units and organization, e.g. centralized pattern shops. The article is concerned with the economic aspects of such organizational changes, the advantages to be gained and the balance with delivery costs over areas of various sizes.—M.T.

Papers on the mechanized foundry: Cope removal, knocking out, sand-blasting, mould washing and heat treatment of castings G. Somigli (*Fond. Ital.*, 1959, **8,** Sept., 320–329) The paper describes various methods used to carry out the above operations.

Internal organisation of small and medium size foundries and the importance to them of technical training G. Barghiesi (*Fond. Ital.*, 1959, **8,** July–Aug., 261–265) The writer gives examples of metal wastage which occurs. A great deal of this could be avoided by better diffusion of technical information, better facilities for instruction and better organization, all more particularly in the small and medium-sized foundries. Methods of achieving this are suggested.

Improvement in production techniques for machine tool castings I. A. Onufriev (*Lit. Proizv.*, 1959, **9,** (2), 16–23) This article is devoted to improvement in the design of casting systems and of castings, methods of mould and core preparation, and moulding box design, and their simplification, carried out at the Stankolit Works since the start of production in 1931. Output of castings in 1958 amounted to 2·4 t per m² floor space, 3·6 t/m² operational area and 8·6 t/m² moulding floor area. Output increased by 74% between 1950 and 1958. Output per man for 1958 was 44 t castings, per operational worker 80 t and per moulder 282 t per annum.—M.T.

The contribution of the Stankolit Works to foundry production P. F. Kuleshov (*Lit. Proizv.*, 1959, **9,** (2), 2–4) A history of this

engineering works on the outskirts of Moscow since the start of its construction in 1930 to the present time shows that the output over a 25-year period amounts to 1 135 000-t castings. Annual output for 1963 is planned at 80 000-t castings per annum after reconstruction and modernization of parts of the plant.—M.T.

Foundry research and development in the post-war period J. G. Pearce (*Found. Trade J.*, 1959, **106**, May, Special No., 9–14, 24) Recent developments in cast-iron compositions, melting and moulding practices, new processes, steelfounding and non-ferrous research, productivity, health, and safety matters are discussed.—A.G.

Modern foundry mechanization J. Bain (*Found. Trade J.*, 1959, **106**, May, Special No., 29–34) The units of a modern mechanized foundry are discussed, including mould making, shake-out, conveyor systems, and core making. A typical layout is presented.—A.G.

Modernized steel foundry boosts production capacity R. H. Herrmann (*Foundry*, 1959, **87**, June, 72–79) The production facilities at the expanded and modernized foundry of LFM Mfg. Co. of Atchison, Kansas, are described and illustrated.

Developments in melting equipment for iron founders W. J. Driscoll (*Found. Trade J.*, 1959, **106**, May, Special No., 20–24) The advantages of hot blast make this the major post-war development. Other items reviewed include water cooling, the slag lined cupola, and electric melting.—A.G.

Notes on cupola furnaces in general and metallurgical blast cupolas in particular: Part I G. Somigli (*Fond. Ital.*, 1959, **8**, April, 125–134) This part deals with cupola furnaces in general and recent improvements. The functioning of hot blast cupolas, basic lined cupolas and water-cooled cupolas is then described.

Heat recovery in a foundry rotary furnace R. de Angelis (*Calore*, 1959, **30**, Jan., 19–26) The furnace described is a horizontal basic lined rotary furnace for production of commercial and alloy steel. It is the only one of its type and capacity at present in use in Italy.

Metal casting furnaces. Part 8 (*Fond. Ital.*, 1959, **8**, Jan., 18–25) A description is given of plant, construction, charging and firing systems, and preparation of burdens.

Investigations into the desulphurization of cupola pig iron by sodium carbonate T. Dumitrescu, S. Stefanescu, and N. Iatan (*Metal. Constr. Masini*, 1959, **11**, (5), 361–366) From experiments in the laboratory and on an industrial scale it may be concluded that the time needed for desulphurizing small amounts (80–100 kg) pig iron by Na_2CO_3 is 8–10 min and larger amounts (300–500 kg), 10–25 min. The optimum quantities of Na_2CO_3 are between 0·5 and 1·0%. Any greater proportion is wasteful. The degree of desulphurization varies directly with the sulphur content During the operation the sodium slag must not come into contact with the cupola slag or with the other acid materials.

Experiments in the premalleablization of pig iron in Czechoslovakia (*Metalurg. Constr. Masini*, 1959, **11**, (5), 407, from *Hutnik*, 11/1957; 2/1958; 11/1958) Premalleablizing tests on conversion pig iron were carried out initially by a continuous process in air, later by means of oxygen supplied to the ladle and finally by oxygen to the ladle plus additions for malleablizing and desulphurizing. These experiments are still in their initial stages.

Tin effect on structure and properties of flake and nodular graphite cast irons E. C. Ellwood (*Mod. Castings*, 1959, **36**, July, 73–80) It was found that Sn had a marked effect in eliminating ferrite from the matrix of grey and nodular irons; in amounts sufficient to give a substantially pearlitic matrix in grey or nodular iron Sn had no detrimental effect on mechanical properties. Results of previous work, and of an investigation at Batelle Memorial Institute are cited.

A diagram for describing the composition, structure and strength of pearlitic iron A. A. Zukow (*Prz. Odlew.*, 1959, **9**, (7), 226–227) The diagram gives the above properties against casting thickness and shape. The author gives the method by which the diagram was constructed, the theory and how it is to be used.

Modification of the structure of cast iron by additions of tin W. E. Hoare (*Met. Corr. Ind.*, 1959, **34**, May, 197–203) It is shown that small additions of Sn can increase the pearlite constituent of the matrix, both with lamellar and with nodular graphite irons, and that larger amounts of Sn can be present without promoting the formation of massive cementite.

You can use malleable iron castings for 1 200°F service (*Steel*, 1959, **144**, June 29, 85) It is reported that research on ferritic and pearlitic malleable irons has shown them to be suitable for valves, fittings, pressure vessels, flanges, and other parts for service at elevated temperatures. Stress-rupture strength at 800°F is equal or superior to that of other ferritic cast materials. At 1 000° and 1 200°F their strength is adequate for many uses.

Steel castings—their manufacture and use C. J. Dadswell (*Found. Trade J.*, 1959, **106**, May, Special No., 41–47) A survey of practice and materials.

Production of steel castings of 3·5% nickel for use at temperatures up to 100°C C. Galletto (*Fond. Ital.*, 1959, **8**, Feb., 45–46, 48) A general description is given of the production of castings for use at temperatures up to 100°C. In addition the writer gives his personal observations on ways of obtaining the necessary resistance properties for use at temperatures below zero.

An investigation of the cast metal of steel anvil blocks I. I. Kon, G. A. Maksimenko, P. G. Novikov, N. V. Fiksen, and M. V. Frolova (*Lit. Proizv.*, 1959, (1), 44–46) In view of the appearance of large cracks in heavy steel anvil block castings of 73 t unfettled weight, the properties of the cast metal and the causes of the formation of the cracks were investigated. The main cause proved to be the formation of thermal stresses in the heated casting during heat treatment. Cracking is promoted by the extremely marked divergence in chemical composition and mechanical properties of the metal over a cross-section of the casting, brought about not only by segregation of the components but also by the penetration into the heart of the casting of carburized metal from the dead-head which comes into contact with the high C-content metal used for final flushing. Lack of chemical homogeneity is also increased by incorrect use of chills. Numerous resultant shrinkage and segregation faults thus cause poor mechanical properties.—M.T.

The casting of shot-blasting turbine parts in high manganese steel P. L. Shirokii (*Lit. Proizv.*, 1959, (1), 48) At the Tashkent Locomotive and Wagon Repair Works, turbine impeller blades for shot-blasting were formerly cast in 3–4%Cr chill cast iron; the life of the blades was 20–25 h and of the impeller and liner 50–60 h. Casting in high-Mn steel increased the blade life to 60–80 h in the as-cast state and 100–120 h after hardening at 1 100°C, and impeller life to 150–200 and 300 h respectively.—M.T.

Steel castings for the aircraft industry Quality requirements Y. T. Elizondo (*Mod. Castings*, 1959, **35**, June, 359–365) Experience in the aircraft industry over the past three years is reviewed to assess results of several steel casting designs, and some recommendations for improving results are made.

Various forms of transport in the circulation of moulding sand R. Jacquemart (*Fond. Belge*, 1959, **29**, May, 139–144) Examples are given of the mechanical handling of the sand by means of elevators and conveyors through various stages of its preparation, distribution, and reclamation.

Experience in the use of clay paste in the preparation of moulding mixtures N. F. Rodin and A. G. Shilova (*Lit. Proizv.*, 1959, **9**, (2), 43) At the Nikolaev Shipbuilding Works, clay was previously added to moulding mixtures as a powder after fine milling and drying. Experience in its addition in paste form (30 wt.% water and 70 wt.% clay) with 30 min mixing time showed that the compression strength of moulds and cores was considerably greater, while gas permeability and tendency to crumbling remained about the same. It was possible to reduce the clay content of mixtures with a 30% saving in consumption.—M.T.

Improvement in the quality of moulding mixtures by means of the introduction of small additions of salts A. A. Gorshkov, B. I. Markhasev, A. N. Byak, and V. V. Studzinskaya (*Lit. Proizv.*, 1959, **9**, (2), 34–38) The aim of the research was to study the conditions of activation of clays, i.e. the changes produced in the composition of the ionic complex by the introduction of small additions of salts to moulding mixtures of quartzite sand with various bentonites and clays. The added salts were Na_2CO_3, NaOH, NaCl, $Na_4P_2O_7$, $1OH_2O$, CH_3COONa, $Na_2C_2O_4$; K_2CO_3, KOH, KCl; $Ba(OH)_2$; $Al_2(SO_4)_3$, $Al(OH)_3$; $Fe(OH)_3$, HCl, CH_3COOH, H_2SO_4, H_3BO_3, citric acid; and $CaCO_3$ and $Ca(OH)_2$. It was found that in order of activation of bentonite the cations have the following sequence: $Na^+ > K^+ > Ca^{2+} > Fe^{3+} = Al^{3+} = N > H^+$, where N is the initial state of the mixture, while the most effective activators were NaOH, Na_2CO_3, K_2CO_3, $Na_2C_2O_4$, and $Na_4P_2O_7$, $1OH_2O$, at an optimum pH value of 9·5–10·5. Tests of the mechanical strength of moulds and cores were also carried out in the green and dry states, and production tests were completed. In the light of the sundry experiments it may be concluded that such activation is economic, in view of the reduction in clay consumption and the improvement in the surface quality of castings and the reduction in scrap.—M.T.

Possible methods of measurement of the humidity of moulding mixtures by electrical means A. Pach (*Prz. Odlew.*, 1959, **9**, (1), 2–9) A critical review is given of possible methods of measurement of the humidity of moulding mixtures by electrical means; they are compared with other methods which are briefly enumerated. The use of electrical methods is not only suitable but necessary as a means of effecting automization in foundry practice. A theoretical analysis is made of such methods as are already employed, and their agreement with empirical data already obtained is indicated. Attention is drawn to the possible evolution of methods based on interatomic reactions. At the present time use of methods based on changes in the dielectric constant is recommended. The other methods described are based on absorption of β-rays, neutron scattering and bombardment, magnetic resonance of the H-atom, electrical conductivity, and dielectric losses.—M.T.

The influence of different factors on the permeability and green strength of synthetic foundry sands L. Lewandowski (*Prz. Odlew.*, 1959, **9**, (8), 245–250) The article gives the results of research done on the influence of the following factors on the permeability and compressive strength of synthetic green moulding sands: (a) Quality and quantity of binder. (b) Size and shape of grains of sand matrix. (c) The addition of coal powder and dextrin.

A new anti-scab parting material P. V. Chernogorov, Yu. P. Vasin, and A. V. Bobrov (*Lit. Proizv.*, 1959, (1), 4–5) Results are given of experiments in the use of slag containing Ca orthosilicate formed in the production of carbon-free and low-carbon Fe–Cr by the silico-thermic method. The main component of the slag (81% $2CaO,SiO_2$) has high strength at elevated temperatures, and the slag forms a fine powder (50–70 μ) at 700°C due to the change in form of $2CaO,SiO_2$. The m.p. of the slag is 1 500–1 600°C. It may be used in powder form as a parting dust or in liquid form as a core paint.—M.T.

An apparatus for determining the strength properties of metal mould coatings V. S. Krasovitskii, I. V. Raspopov, and R. M. Egnus (*Lit. Proizv.*, 1959, (1), 47) The apparatus described is intended to measure the strength of coatings on ingot moulds and moulds for rolling mill rolls, pans, and slag pots, and also the tenacity of the bond with the metal surface. The coating is applied to the outer surface of two nuts on a cylinder, and the layer of coating has to resist the scraping action of a sleeve passing over the nuts.—M.T.

An analytical assessment of the working process of sandblowing, moulding and core-making machines P. N. Aksenov (*Lit. Proizv.*, 1959, (1), 15–20) Problems to be solved during operation of these machines are set out and formulae derived for the calculation of their

operational conditions, on the basis of the aerodynamics of the process; and a method of calculation of sand comsunption is presented.

An investigation of the blowing time for cores and the consumption of air-sand mixtures in the core-blowing process V. G. Rakogon (*Lit. Proizv.*, 1959, (1), 21–23) Two phases should be distinguished during this process—the stable and unstable. Compacting of the mixture in the box occurs during the unstable phase. A study is made of the latter with bottom and top air outlets. By the experiments it was established that in general this unstable movement period may be divided into two parts: the filling of the core box and compacting of the mixture in the box as a result of the kinetic energy of the air-sand stream and the increase in pressure inside the corebox and the compacting of the mixture in the upper part of the box and in the inlet apperture under the action of further pressure differentials between the inlet pressure and that inside the box and that between the reservoir and the inlet pressures.—M.T.

How to avoid sand segregation AFS Sand Division Committee 8–F and National Industrial Sand Association (*Mod. Castings*, 1959, **36,** July, 62–64) The results of a joint investigation by these bodies showed that sands of high clay content segregated less than those with little or no sand; dry sands tended to segregate much more than damp sands, and material with wide grain size distribution segregated more than sands with a narrow range.

Rotating moulding-sand-delivery machines for filling foundry flasks and casting pits V. A. Shcherbina (*Lit. Proizv.*, 1959, (1), 25–27) A satisfactory method of supplying sand to the moulding platforms for filling mould-boxes for heavy castings is an important form of mechanization in heavy foundry work. Descriptions are given of several machines, rotating, fixed, and mobile (or combinations of these features) for belt delivery of sand for the moulding of heavy castings up to 100 t. The design of casting platforms is also shown.

Reclaim sodium silicate bonded sand G. C. Warneke (*Mod. Castings*, 1959, **35,** June, 375–379) Reclamation tests showed that a casting from green sand will in general give less dimensional stability and a greater as-cast tolerance range than one cast in reclaimed sodium silicate-bonded sand.

Crust separation test for investigating sand expansion defects P. W. Goad (*Mod. Castings*, 1959, **36,** July, 86–98) This test consists of exposing the specimen, consisting of a narrow strip of a flat sand face, suddenly to a source of intense radiant heat, such areas behaving as if they were covered by broad metal streams. The method of carrying out the test is described, and its application to the study of expansion defects is discussed with examples. (12 refs).

Gating of sand castings J. S. Abcower (*Metalen*, 1959, **14,** (2), 18–21) A theoretical treatment.

Calculating feederheads for steel foundries M. Notte (*Fond. Ital.*, 1959, **8,** Sept., 305–313) Determining the size of feeder heads has always been a difficult task. The Pellini method described in this article has proved to be rapid, economical, and accurate in daily use even for castings of thicknesses up to 57 cm.

A gating system for pile moulding I. Ya. Polykovskii (*Lit. Proizv.*, 1959, (1), 46–47) Single runners for pile moulding are liable to create excessive pressure in the lower tiers. The author outlines the system he has evolved for self-sealing of the individual tiers by means of conical cores which float on the surface of the metal. When the core is in the vertical position the metal is fed to the lower tiers through a hole in its centre. These self-sealing core traps have proved satisfactory in service; flat plate traps have also been satisfactorily used.—M.T.

Proper gating through use of cobalt 60 A. J. Karam (*Mod. Castings*, 1959, **35,** June, 353–358) Non-destructive testing using ^{60}Co has improved casting quality at the Central Foundry Div. of GMC, by (1) checking new casting design before use, (2) improving gating design, (3) establishing inspection standards. Illustrated examples are given.

Gating technique in the riser-gate casting process A. Holzmüller (*Giesserei*, 1959, **46,** Sept. 24, 545–551) The theoretical basis of the process and its advantages are reviewed and examples of design and application are given.

Exothermic substances for feeders K. Korecki and T. Welkens (*Prz. Odlew*, 1959, **9,** (7), 218–224) First the effect of these materials is described; the author then goes on to describe several foreign (non-Polish) antipiping materials giving their method of use, and comparing and evaluating them. In conclusion, work in Poland in this field is described.

Experience in the application of increased gas pressure to risers P. I. Jamschanow (*Iron Steel*, 1959, **32,** May, 181–184) A translation of a paper from a symposium 'Hochwertiger Stahlguss' which is itself a translation from Russian. It deals with the calculation of the thickness of the casing and charge weight of a cartridge of chalk added to the riser as a source of gas supply during solidification of the casting, these factors being calculated to ensure that gas is evolved so as to achieve uniform density in the casting.

Atom gage reads mold moisture (*Iron Age*, 1959, **184,** July 9, 97) A radioactive source emits fast neutrons which on collision with the hydrogen nuclei of water atoms in the sand produce slow neutrons. The number of these is directly proportional to moisture content and is determined electronically.—A.G.

The newer processes in mould and core production J. B. McIntyre (*Found. Trade J.*, 1959, **106,** May, Special No., 67–62, 78) Developments discussed include the CO_2 process, investment moulding, plaster and shell moulding, and precision processes.—A.G.

Automatic coreblowing machine (*Ind. Gas*, 1959, **22,** Aug., 14–15) A design by Foundry Equipment Ltd, is shown and briefly described.

Moulding of rapidly binding materials based on waterglass J. Wojtow (*Prz. Odlew.*, 1959, (6), 173–178) The article considers research and application of fast-setting moulding materials based on waterglass. Polish raw materials were used. Laboratory tests gave the relationships between strength and porosity and setting time as well as percentage contents of waterglass and clay.

The use of rapid drying mixtures for casting large components P. G. Vinnichenko and I. I. Kumilin (*Lit. Proizv.*, 1959, **9,** (2), 43) At the Riga Railway Wagon Works, use is made of waterglass for mould preparation for sundry wagon and carriage components up to 450 kg and heavy parts up to 3 t. Use of a clay-sand mixture produced very scabby castings with sub-surface blow-holes, sand and other non-metallic inclusions and surface oxides, which were in large measure eliminated by use of the sand-waterglass mixture. This was especially marked on 2·2 t glue press cylinder castings working at 350 atm. The green compression strength of the mould mixture (8–9% waterglass, 0·56% fuel oil) is 0·25–0·30 kg/cm^2 and of the core mixture (7–10% waterglass, 10% sawdust or fine shavings), 0·17–0·20 kg/cm^2. Caustic soda is not used.—M.T.

Studies on the carbon dioxide process H. Miyasaka (*Imono*, 1959, **31,** June, 571–576) Domestic and imported Na_2SiO_3 binders gave equivalent results for strength and permeability. The moulds, on standing in the atmosphere, showed instability within a few hours and then a gradual rise in strength. The gas pressure generated from a given weight of mould is greater than with other moulds,/but the vol. is smaller and is generated gradually. The Na_2SiO_3–CO_2 reaction is almost complete within 30 sec of gassing.—K.E.J.

The preparation of hollow cores in sand-resin mixtures L. M. Pomerantsev (*Lit. Proizv.*, 1959, **9,** (2), pp.44–45) The use of hollow cores represents a valuable saving in expensive thermoplastic resins, reduces burning of the resin and ensures the extraction of gases from the molten metal. Existing methods of production have various disadvantages. By the method described a single aperture serves to blow in the core mixture and to remove the core by compressed air. The machine is described and illustrated; cores prepared with it from a mixture of sand, 8% resin, or powdered phenolic resin, 1% hexamethylenetetramine, and 0·3% talc had a tensile strength of 15–18 kg/cm^2.—M.T.

The application of a 'Tertal 30/10' oil core binder in a steel foundry K. Szubert and J. Ptyel (*Prz. Odlew.*, 1959, **9,** (8), 253–256) The binders used hitherto such as linseed oil, 'C' oil, 'W' oil, tall oil, and '121' urea resin are discussed. The properties of the new binder (TERTAL 30/10) are given with a description of its application in core sands. This new binder is used with silica sands and can be used with clay additions to increase its green strength. Methods of drying core sands, the hygienic and safety conditions and the advantages of the new binder are also discussed.

Investment Casting Institute Standards II. Visual, penetrant and magnetic particle inspection (*Prec. Met. Mold.*, 1959, **17,** July, 40–41) The classification of irregularities and their evaluation is discussed for visual, penetrant, and magnetic particle inspection.—A.G.

Mechanical properties of investment cast 410 W. F. Carn (*Prec. Met. Mold.*, 1959, **17,** July, 34–36) An investigation has been made of the effect of varying tempering temperatures on the properties of investment cast 410 stainless steel. Results are tabulated.—A.G.

Casting of tools by the lost-wax method L. P. Brontvaine and V. I. Krylov (*Lit. Proizv.*, 1959, **9,** (2), 45) For precision-cast fitters' tools, waterglass treated with NH_4Cl is used as a binder for the first two or three layers of ceramic coating and on the subsequent layer untreated waterglass diluted to dens 1·27–1·3. The quality of the moulds reduced mechanical working of the tools by 80–90%, gave considerable metal economy and reduced the prime cost of the tools.—M.T.

Silica binders for investment casting J. I. Evans (*Found. Trade J.*, 1959, **107,** Sept. 3, 113–120) The process is described and the use of ethyl silicate and its hydrolysis and the properties of the sols are outlined.

Suitable fabrication techniques for core boxes and patterns for use in core-shooting machines G. Schneider (*Giesserei*, 1959, **46,** Sept., 565–569) Materials, design, mechanization, and the manufacture of cores by the CO_2 process and from synthetic resin sands are among the topics discussed.

Materials recommended for precision investment castings E.-G. Nickel (*Giesserei*, 1959, **46,** Sept. 24, 542–544) In this report of Technical Committee No.1 on Precision Casting of the Verein Deutscher Giessereifachleute, recommendations are made concerning the use of case-hardening, heat-treatment, tool, and heat and corrosion resistant steels. The recommended form of test-piece for physical testing is outlined.

Carrier uses castings to build air conditioners R. R. Stanton and W. F. Irwin (*Mod. Castings*, 1959, **35,** June, 31–32) Examples are given of some of the range of castings manufactured by Carrier Corp., Syracuse, for air conditioning equipment.

Grain refinement of solidifying metals by vibration R. G. Garlick and J. F. Wallace (*Mod. Castings*, 1959, **35,** June, 366–374) Laboratory-scale experiments on the behaviour of metals solidifying under vibration showed that some grain refinement was obtained in all cases, but that refinement was greater for metals showing larger solidification contraction. The mechanism is discussed, with reference to solid solutions and eutectics. Grey cast iron, with a small solidification expansion is refined only slightly (16 refs).

Shell moulding bibliography (*Engineering Societies Library, ESL Bibliography*, No.13, 1959, pp.26) A select annotated list 1952–58 in alphabetical order of authors (or of titles of anonymous papers).

Shell mould castings offer many design advantages (*West. Metalw.*, 1959, **17,** May, 19–22) After an account of the advantages and fields of application of shell moulding, some problems encountered in the process are mentioned. These include carbon pick-up from the organic binders, pattern cost, and shell warpage.—A.G.

A two-position semi-automatic sand blower for the preparation of shell cores A. M. Nei-

mark (*Lit. Proizv.*, 1959, (1), 24–25) The machine described in detail was designed for the preparation of complicated cores for the deflector plates of centrifugal pumps from a resin-sand mixture.—M.T.

New foundry resins and application techniques for shell moulds and shell cores W. C. Capehart (*Mod. Castings*, 1959, **35,** June, 329–336) A review of new pulverized and liquid type foundry resins, problems in their use and control tests, is given.

Report on an investigation of the shell casting method K. Koolstra (*Metalen*, 1959, **14,** Aug. 31, 242–245; Sept. 12, 258–260) This paper is a general description of the shell method of casting iron and steel originally developed in Germany by J. Croning in 1937 and later taken over by the Americans who developed it further on mass production lines. There are numerous curves and illustrations in the text. The various relationships between temp., grain size of moulding sand, hardening times, shell thickness, moisture content, mixing, etc. are touched upon and, to conclude, the advantages and disadvantages of the method are outlined.—F.R.H.

Pre-coated sands in the shell moulding process E. Laviosa (*Fond. Ital.*, 1959, **8,** Jan., 9–12) This article sets out to establish the properties of precoated sands as a guide to technicians intending to use them. By way of comparison the traditional method using a mixture of powdered sand and resin is described.

Causes and mechanics of the scum defect G. J. Vingas and J. B. Caine (*Foundry*, 1959, **87,** June, 94–97) It is shown that the sources of scum defects, formed on the surfaces of sand castings are the deoxidizers used. Factors influencing formation and possible remedies are discussed.

The effect of pouring rate, mould-hardness, moisture of mould and pouring temperature on scab in synthetic sand moulds U. Harada, K. Nishiyama, and T. Kubota (*Imomo*, 1959, **31,** June, 561–571) The mould hardness influences green properties and hot compressive strength. The severity of scab in such moulds varies in proportion to the mould hardness, moisture content of the mould, rate of pouring and pouring temp. In the mould, expansion caused by shock heating is greater with a lower moisture content.—K.E.J.

Generation of residual stress in iron castings T. Owadano (*Imono*, 1959, **31,** June, 583–588) The residual stress in a linked pattern of cooled bars is caused by the last of a stress series of compression–tension–compression–tension. The 'critical temp.' should be taken to be the transformation temp.—K.E.J.

Investigations into the evolution of gas from moulding mixtures and cores at high temperatures L. Sofroni, E. Cohn, and C. Cosneanu (*Metalurg. Constr. Masini*, 1959, **11,** (5), 367–373) Laboratory experiments are described for measuring the evolution of gases and air from different mould mixtures as a function of weight, temperature, percentage of different binders, etc. Tables are given showing the advantages of certain binders as opposed to dextrin and linseed oil.

The causes of moulding matter and sand inclusions in thin-walled iron castings and their effects in enamelling P. Göbbels (*Inst. Vitr. Enam. Bull.*, 1959, **10,** Sept., 158–162; from *Mitteillungen*, 1958, May) The mechanism of the formation of porosity by inclusions is discussed and illustrated. Staining occurs which can be removed by annealing but the porosity is not removed.

The avoidance of scrap due to hot cracking in fan hub castings N. N. Lisetskii (*Lit. Proizv.*, 1959, (1), 47) These castings, 2200 kg in weight, were originally cast in 35 LP steel without a central aperture with a heavy central dead-head. After machining out the central aperture, cracks were found ¼–½ the thickness of the boss caused by flame cutting off of the dead-head, which were no longer apparent on changing to mechanical cutting. A change was then made whereby the heavy central dead-head was replaced by three open risers and internal chills, while the central aperture was filled by a core coated with chrome iron ore. The accuracy of its centring was attained by the position of the chaplets. Output of sound castings increased by 14% and the unfettled weight of the castings was reduced by 80 kg.—M.T.

New techniques for studying the fluidity of molten metal and the formation of shrinkage cavities I. Chikel' (*Lit. Proizv.*, 1959, (1), 27–32) A discussion of the results obtained from the casting of a new type of arfa test-piece and of spherical test-pieces, which throw light on the problems of mould filling and feeding of the casting during solidification, and the avoidance of shrinkage cavities is presented.—M.T.

Bins and low lift trucks in the foundry S. Komorowski (*Prz. Odlew.*, 1959, **9,** (1), 9–13) Transport along the level in foundries cannot always conveniently be effected by belt conveyors, and the use of bins and low lift trucks, and occasionally high lift trucks, is essential, especially where space is restricted. Cranes are not suitable for the purpose. Various designs of bin, sand hopper, and knock-out grids, on which castings may also be fettled, are shown and described.—M.T.

Clean air for foundries W. H. White (*Foundry Trade J.*, 1959, **106,** May, Special No., 35–40) The dust problems arising in the different operations in the foundry are discussed in relation to the obligations imposed by legislation, and methods of dust suppression are considered.—A.G.

Dust control on fettling benches C. M. Stoch and R. H. Brown (*Found. Trade J.*, 1959, **106,** June 4, 649–651) Work done by BSCRA on exhaust systems, with noise reduction measures, is outlined.

Work study in the foundry W. B. Trenholme (*Brit. Found.*, 1959, July, 314–322) The economies attained in a mechanite foundry by the application of the method are set out. A reduction in core-making and moulding costs of £7–12 per t was achieved.

VACUUM METALLURGY

Practical use of the vacuum furnace for refractory metals A. M. Emyashev (From a symposium *Primenenie Vakuuma v Metallurgi*, 1958, 54–61) Russian equipment is reviewed and a 110-lb furnace for steel melting is described. The production of crucibles and the choice of refractories, the measurement of temperature, and the taking of samples are all considered.

U.S. Steel reveals pilot facilities F. W. Starratt (*J. Met.*, 1959, **11,** Aug., 510–511) The pilot installations demonstrated at the South Chicago works of US Steel include a consumable-electrode vacuum furnace, a vacuum stream degassing unit, a scale-model of a 300-t OH furnace for observing combustion under various conditions, and an experimental 8-t LD furnace. Other plant not demonstrated includes a direct reduction unit using the Nu-Iron process.

Vacuum melting plant (*Mech. World*, 1959, **139,** July, 315–317) An account of Wm. Jessop & Son's new plant for Ti, Zn, and high duty steel is given.

Some theoretical questions about vacuum metallurgy D. S. Kamenetskaya (From a symposium *Primenenie Vakuuma v Metallurgii*, 1958, 49–53) Melting with pressures near the triple point, superheating effects, reactions with gases at low pressures and the choice of pressure and of materials for crucibles, thermocouple sheaths etc. are considered.

Quality aspects in vacuum arc melting E. A. Loria (*Blast Fur. Steel Plant*, 1959, **47,** June, 601–607) A general review of the present position of vacuum arc melting is followed by a more detailed consideration of the consumable arc process. Gas content, surface condition, porosity, and inclusion contents are discussed in relation to vacuum arc melting.

Vanadium-Alloy Steel Co. completes expansion program (*Iron Steel Eng.*, 1959, **36,** June, 135–136, 139) Principal items include a new vacuum melting furnace and rolling mills, a continuous controlled-atmosphere annealing furnace and a 2000-t vertical hydraulic forging press.

Core boxes for shell cores J. E. Stock (*Mod. Castings*, 1959, **36,** July, 71–72) Reasons are discussed for the preference of the John Deere Waterloo Tractor Works of Waterloo, Iowa, for the use of grey iron shell core boxes in preference to Al.

Latrobe Steel Co. starts consumable electrode vacuum arc furnace (*Iron Steel Eng.*, 1959, **36,** June, 132) Design and operation data are given of this furnace, with an annual capacity of 3000 net tons, and capable of producing an 8500-lb ingot.

The effect of vacuum casting on the structure and forgeability of high-nickel ingots K. Radzwicki (*Hutnik*, 1959, **26,** (7–8), 262–267) Ni, even in the solid state, has a considerable tendency to absorb H_2. It has been found, however, that vacuum casting completely eliminates blowholes even where the conditions from the point of view of chemical composition are very bad. Furthermore it was observed that the degassing of high-Ni steel by vacuum casting causes the transcrystalline zone never to exceed one-third of the diameter of the casting. This improves malleability. Also it has been observed that if particular care is exercized in heating before forging, high-Ni steels with high S content can be improved.

REHEATING FURNACES AND SOAKING PITS

Special features of Stelco's new soaking pits E. T. W. Bailey (*Iron Steel Eng.*, 1959, **36,** July, 73–79) Design and control features of the soaking pits installed to serve Steel Company of Canada's new 46-in. blooming mill are described.

Kaolin refractories for soaking pit lids M. I. Dygalo and N. S. Onishko (*Stal'*, 1959, (9), 850–852) Tests on these lids compared with fireclay compositions nearly doubled the service obtained.

Re-heating of special steel billets R. Courdille (*Centre Doc. Sidér. Circ.*, 1958, (5), 1059–1069) The various reheating furnaces for special steels are reviewed and compared. This is followed by a description of a new type of continuous re-heating furnace with distributors. The construction and upkeep are expensive but justifiable by the results obtained. Developments in resistance heating are envisaged; in conjunction with the use of gas or oil, this will permit maintaining desired carburizing or decarburizing atmospheres.—R.F.

Record-size soaking pits at Lukens Plant Lukens Steel Co. (*Indust. Heating*, 1959, **26,** June, 1176–1178) Twelve new soaking pits at Lukens Steel Co., are described. Each pit is 17 ft 9 in. deep, 25 ft. 6 in. long and 11 ft 6 in. wide, with a capacity of 180 t. Ingots up to 61-t can be accommodated. The pits are one way fired with stainless steel heat exchanges preheating the combustion air. Fuel consumption with a cold charge is $1{\cdot}5\times10^3$ B.ThU/t.

Rapid heat acceleration in the soaking pits at Fairless Works J. L. Hagan (*Iron Steel Eng.*, 1959, **36,** June, 95–98) It is shown how the soaking pit operation has been improved compared with similar installations elsewhere due to the heat acceleration principles incorporated in the original design; furnace firing rate is regulated so as to keep rate of heat transfer to the centre of the ingot to a maximum.

Dolomite thrower takes on new job (*Steel*, 1959, **145,** July 13, 116) A mobile dolomite throwing machine is used to throw sand into billet reheating furnaces to effect regular bottom repairs.—D.L.C.F.

Dolomite machine throws sand (*Iron Age*, 1959, **184,** July 16, 109) An OH fettling machine has been converted to supply a 4-in. bed of sand on the floor of a billet reheating furnace. Delivery rate is 1200 lb of sand per min.—A.G.

Plate mill furnaces *The Society of Furnace Builders* (*JISI*, 1960, **194,** March, 365–383) [This issue].

The modern reheat furnace and the possibilities of improvement of Polish reheat furnace work Z. Warczewski (*Hutnik*, 1959, **26,** (7–8), 276–288) In Poland, twin-cell multi-burner reheat furnaces are mainly used which are behind the general progress in this field. The author blames the lack of progress on: bad co-operation between steelworks and reheat furnaces, lack of co-ordination planning of casting which should be supplied by the steel works and unexpected servicing closedowns

etc. All this makes the operation of reheat furnaces difficult as they should work in a rhythmic and stabilized manner. Only recently, as an experiment, modern furnaces have been introduced in Poland, but so far the practical results are not satisfactory.

Short flame high pressure nozzle V. D. Esipov (*Metallurg*, 1959, (2), 28–31) A description is given of a redesigned burner for sheet mill batch furnaces for reheating slabs weighing up to 5·5 t. The furnaces are designed for blast-furnace and coke oven gas heating (2 200–2 500 kcals/m³). Maximum heat input to the furnace is 7·5–8·0 million kcals/h. These furnaces have recently been changed over to gas and fuel oil firing. Ten high pressure burners (five on each side) with 'twin straight jet atomization' have been installed. These burners are described and illustrated in detail in this article—R.S.

HEAT TREATMENT AND HEAT-TREATMENT FURNACES

Recent heat treatment furnace installations (*Metallurgia*, 1959, **59,** June, 275–294) An extensive illustrated survey of conventional and vacuum furnaces and of reheating, stress-relieving, annealing, carburizing, and nitriding hardening and tempering equipment. Salt and lead bath, induction, sintering, and brazing installations are then reviewed.

Automatic control of the heating process of continuous and chamber heating furnaces M. D. Klimovitskii and B. I. Sinchuk (*Metallurg*, 1959, (5), 38–42) Automatic control schemes are suggested for continuous furnaces ensuring the control of temperature in the working space, of the ratio fuel/air, of the pressure in the working space of the furnace and the pressure and calorific value of gases for gas heater furnaces, and the pressure and temperature of fuel oil fed to other furnaces. For chamber furnaces ensuring control of temperature in the different zones of the furnace; air/fuel ratio and pressure in the working zone. Block diagrams are given.

The influence of furnace pressure control on the performance of regenerative reheating and heat-treatment furnaces J. A. Grainger and G. Wood (*JISI*, 1960, **194,** March, 307–319) [This issue].

How to maintain and certify heat treat furnace controls R. M. Lady and R. G. Matthews (*Steel*, 1959, **145,** July 13, 106–107) New methods and equipment are described which enable instruments to be cleaned, overhauled and calibrated without disrupting production. Instruments are connected by plugs which allow immediate replacement. A fitted laboratory test-bench simplifies testing and fault-finding. Portable test carts simplify furnace surveys.—D.L.C.P.

The flame: Flame radiation F. Savioli (*Met. Ital.*, 1959, **51,** June, 139–142) This third article in a series deals with flame radiation and spectrum analysis to determine the instantaneous composition of the gases and the progress of reactions.

The one-dimensional theory of furnace heat transfer D. B. Spalding (*Fuel Soc. J.*, 1959, **10,** 8–17) A formulation of Thring's heat transfer method to permit rapid computation is given. Gas and roof temperatures can often be calculated. An example is given.

Investigating the non-oxidising heating in the flames of furnaces without muffles A. I. Vashchenko and A. G. Zen'kovskii (*Chern. Metallurg.*, 1959, (2), 127–133) Furnaces for non-oxidizing heating fed with high calorific gaseous fuels must operate with a coefficient of air consumption not above 0·55. The burners must ensure good air and gas mixing. It is advisable to preheat not only the air but also the gases. In the furnace chambers the complete burning of the primary combustion products should be carried out immediately beyond the air preheaters and in continuous furnaces, in the zone of preliminary heating of the metal.

Controlled atmospheres V (*Trattamenti Termici*, 1959, **2,** May–June, 19–21) For pilot plants, small-scale production or laboratory research the use of endothermic generators fed with CH_3OH rather than methane or propane is favoured. The costs (in Italy) of various methods are compared: direct feeding of alcoholic mixtures, endothermic generator fed with town's gas, cylinder gas, and endothermic generator fed with methanol. The latter method is favoured, its main advantage being the ability to add carburizing gas and thus vary the carbon content. For the diffusion phase gas can then be used without hydrocarbon enrichment.

Preparation and use of a protective atmosphere of technically pure nitrogen B. M. Estrin and E. N. Bertol'man (*Stal'*, 1959, (9), 854–861) Liquid ammonia is used as source and is dissociated on a non-sintering Ni–Fe catalyst on a carrier of Al_2O_3. The development of this type of catalyst and alternatives with other inert carriers and their operation are described. Removal of O_2 from technical N_2 by catalytic means is also made use of. The use of the gas and the furnaces used are also indicated.

High strength stainless alloys need close control of hydrogen, argon atmospheres R. L. Ray (*Western Metalw.*, 1959, **17,** June, 54–56) The heat treatment of hardenable stainless steels is dealt with. Four points must be considered: surface conditions, dimensional considerations, structural properties, economics. Bell-type furnaces are best for hardening in protective atmospheres of H_2 or A. Processing in dry H_2 may be economic.—D.L.C.P.

Heat treatment queries answered C. Doescher (*Metalw. Prod.*, 1959, **103,** April 3, 591–594) A number of practical questions on heat treatment are answered by a hardening shop foreman.

Heat treating discussions at the 1959 Western Metal Show T. A. Dickinson (*Met. Treating*, 1959, **10,** May–June, 4–5, 38) A variety of topics is briefly treated, including the prevention of warping, atmosphere control loss of ductility in heat-treated welds and explosive forming.—A.G.

Forced-air circulation at 1100°C Hedin Ltd (*Sheet Met. Ind.*, 1959, **36,** June, 434–436) An electric furnace to operate up to 1100°C with a tolerance of ±10° is described.

How to avoid trouble with type 431 stainless C. C. Angstadt (*Met. Progress*, 1959, **75,** June, 86–91) The necessity for careful heat treatment in H_2-free atmospheres to obtain satisfactory properties in this martensitic stainless steel is emphasized. Characteristics of the steel and data relating to heat treatment and structures produced are given.

New heat treat laboratory serves customers' needs (*Iron Age*, 1959, 183, June 11, 142–143) A description is given of a heat treatment laboratory set up by a firm manufacturing furnace equipment. Production equipment is used to investigate clients' requirements and to undertake research—A.G.

Conference on hardening in high-temperature media and the intermediate transformation of austenite B. I. Elizarov, D. M. Pomerants, and V. V. Skotnikov (*Metallov. Obra. Met.*, 1958, (5), 58–63) Abstracts of papers are given.

Case hardening D. Flament (*Mét. Constr. Méc.*, 1959, **91,** June, 459, 461, 463) This section deals with box case-hardening and cyaniding. Some data on steel compositions, depth, and hardness of case and cyaniding bath compositions are given.

High temperature carburizing (*Wild-Barfield J.*, 1959, **7,** Sept., 2–7) Work at 1000, 1050, and 1100° is reported on En 32 types of steel. Cracked NH_3 and propane was used or endo-gas and propane. Case depths are given and the prospects for industrial use of the process are discussed.

Carburizing controls improve quality of truck parts C. H. Shelton (*Iron Age*, 1959, **183,** June 25, 104–105) Operation of a large pusher-type gas carburizing furnace is described.—D.L.C.P.

Advantage of liquid carburizing A. F. Holden (*Ind. Heat.*, 1959, **26,** June, 1156–1158) The following characteristics of liquid carburizing are explained: rapid penetration, selective carburizing, uniformity, minimum distortion, accurate control, direct quenching, water soluble bath, high production rates. A series of curves compare case-depths for different times and temperatures.—D.L.C.P.

Controlled carburization increases life of drill steel F. Anderson (*Met. Treating*, 1959, **10,** May–June, 8, 42) A new process hardens both the external and internal surfaces of hollow drill rods while the central annulus remains tough and impact-resistant.—A.G.

Control of the carbon content in the cemented layer E. M. Morozova and F. R. Florensova (*Stanki, Inst.*, 1959, (9), 31-34) Cementation in a solid carburizer in stages makes it possible to control the carbon content in the layer. The process is carried out in two stages; at high temperatures, to form the layer with a high carbon concentration and at a lower temperature further to increase the thickness of the layer and to reduce its carbon content. For a 0·7–1·0 mm layer a first stage of 1 h and a second stage of 2 h is recommended; and for a 1·1–1·5 mm layer a first stage of 2 h and a second stage of 2–3 h have given good results.

Hardening of metal surfaces G. Grenier (*Echo Mines*, 1959, Aug., 449–451, Sept., 507–508, 513) A review of steels and cast irons and some non-ferrous alloys.

Flame hardening and flame softening (*AWS bibliography*, 1958, pp.3) References are given in chronological order to papers in the *Welding J.*, since 1940.

Progress in induction heating in Japan S. Ishida (*Trattamenti Termici*, 1959, **2,** May–June, 15–18) The article describes hardenability tests of steels S35C (0·33%C), SNC 2 (0·28%C, 2·61%Ni, 0·73%Cr) SCM1 (0·28%C, 1·17%Cr, 0·28%Mo), cooling by water jet and tendency to stress, and research into stress in gears hardened by induction. The best conditions for producing gears by burnishing with induction heating are described. This latter method is claimed to produce better mechanical characteristics and to reduce production costs.

Roll surface hardening by the use of induction heating I. Zlatník (*Hutn. Listy*, 1959, **14,** (5), 421–429) The technology employed with rolls for cold rolling, in Czechoslovakia and several other countries, is discussed.—P.F.

The development of the nitriding process G. J. Cox (*Trattamenti Termici*, 1959, **2,** May–June, 3–13) The writer summarizes the advantages of the processes and lists significant publications on the subject. Attempts to make the process more rapid and economical are described together with the nitriding of pig iron, high-alloy, and tool steels. An account is given of recent work on the urea process, on the effect of dissociation of ammonia, high-pressure nitriding, Ionitriding, and renitriding. The conclusion is that no notable progress has been made and methods used tend to be too complicated for economical working. Recent research has proved that the process is more economical using ammonia with more conventional methods.

Sulphonitriding—the method for increasing wear resistance A. Pospisil and F. Hasil (*Czech. Heavy Ind.*, 1959, July, 38–42) The theory and practice and advantages of the sulphonitriding process are reviewed. H_2S, and N_2 (from dissociated NH_3) are passed over suitably prepared work at over 400°C. The resulting surfaces possess excellent wear resistance and low friction properties.

Luminous wall furnace slashes heat treat costs, boosts quality (*Steel*, 1959, **144,** June 29, 82–83) The use of a luminous wall furnace with internal dimensions 4½ ft dia., 10 ft high, for heat treating missile cases is described. A feature of the furnace is that it can gain and lose temperature very quickly. The Cr–Mo steel weldments are preheated and stress relieved at 1000 or 1300°F and austenitized at 1600°F; they are then quenched and tempered in salt baths. A protective atmosphere can be used in the furnace.—D.L.C.P.

Bogie hearth tilting furnace for annealing castings (*Ind. Gas.* 1959, **22,** June, 12, 14, 15) Replacement of an electric furnace by a gas fired design is described. Stainless steel and Ni alloys are melted. Gas consumption is estimated for a 500 lb charge.

Huge gas-fired stress relieving furnace (*Austral. Eng.*, 1959, **51,** July, 67–68) A furnace with working dimensions 50 ft 6 in.× 16 ft×15 ft with max. operating temp. of 1100°C is briefly described.

A continuous tin-plate annealing line R. G. Rayden (*BTH activities*, 1959, **30,** March–April, 91–96) An illustrated account of the electrical equipment at Velindre.

Radiant heat for preheating and stress-relieving P. J. Cooper (*Weld. Met. Fab.*, 1959, **27,** June, 246–248) The many applications of the portable coiled wire electrical heater, with alumina head insulators are explained. They are particularly useful for heating large welded assemblies. The heaters can be applied to certain areas or whole vessels as required, covered with insulation, connected to a controllable power supply, and used to give an accurate heat treatment.—D.L.C.P.

Annealing forging iron in a liquid medium D. S. Soskin (*Lit. Proizv.*, 1959, **9,** (2), 45) Annealing of forging iron in a fused salts (75%$BaCl_2$+25%NaCl) has been recommended by TsNIITMASh at 1030–1050°C for 1 h. It is suggested that a change in composition to 70–30% be made and also a method of combining the salt bath annealing furnace with the second-stage gas furnace is suggested.

Cyclic annealing of forgings (*Met. Treatment*, 1959, **26,** May, 209–210) An installation of three furnaces carrying out a two-stage annealing cycle at 600–700 and 350–400°C automatically is described.

How to determine continuous annealing line output for different strip widths and thicknesses R. A. Andreas (*Iron Steel Eng.*, 1959, **36,** June, 93–94) Curves and their method of derivation are shown for determining furnace production as a function of furnace line speed for several strip gauges and widths.

Recovery of decarburized mild steel H. L. Couch and J. D. Lubahn (*Trans. Met. Soc. AIME*, 1959, **215,** June, 433–436) Strain hardening resulting from 0·5% strain can be partly removed by subsequent heating even without recrystallization or grain growth. This varies from 5% in 1 h at room temp. to 70% at 800°C. Apart from the Bauschinger effect, tensile behaviour is essentially the same after straining and heating as if there had been less strain and no heating. The bearing of this on deformation and recovery is discussed.

Continuous stress-relief of transformer laminations A. Nicholls (*Met. Treating*, 1959, **10,** July–Aug., 8, 10) After discussion the BTH plant at Rugby is described.

Gas-metal reactions during box annealing of low carbon steel R. M. Hudson and G. L. Stragand (*ASM preprint* 150, 1959, Nov., pp.16) Gas evolution during vacuum annealing was studied. The furnace atmosphere was shown to differ from the gas supplied and that within the coils to differ from both. This must be taken into account in studies on controlled atmospheres.

Improvement of heat treatment conditions for some motor car part forgings A. E. Shebelev (*Metallov. Obra. Met.*, 1958, (4), 45–49) A high deformation ratio in hot stamping (not less than 400–500%) improves the machinability of structural alloy steels. Normalization at not less than 950° and tempering below 630–640° have the same effect. The hardening temperature should be lower in proportion as the degree of deformation in hot-stamping is greater in order to prevent the precipitation of ferrite. Components of carbon steel, should be quenched in water at not below 45–50°.

Isothermal heat treating approach wins savings, quality bonus (*Steel*, 1959, **144,** June 22, 86–87) An improved heat-treating method for eutectoid steel 3 lb rail hooks is described. Previously, the hooks were formed (1700°F), oil quenched, and tempered. In the improved method the part is quenched in molten salt at 650° to obtain a fine pearlite structure.

Progress of closed-quench furnaces J. McMullen (*Metalw. Prod.*, 1959, **103,** July 31, 1179–1182) A review of multi-purpose furnaces for bright-hardening, carbonitriding, and gas carburizing.

The why and how of quenching C. A. Siebert (*Met. Treating*, 1959, **10,** July–Aug., 4–7, 43) A review in terms of the usual diagrams, with data on 18–8.

Twenty years of studies in the tempering of high-speed steels A. H. Michel (*Bull. Cercle d'Etudes, Mét.*, 1959, **7,** June, 463–482) A literature review with a summary (21 refs).

A study on the stress-tempering of carbon steels T. Sakurai, H. Izumi, and T. Kawasaki (*Nippon Kinzoku*, 1958, **22,** Oct., 540–544) With stresses above the yield point, the proportional limit and 0·2% yield strength were improved. The stress-tempering effect is most marked with low tempering temp. and carbon content. At 100–300°C, the high tensile strength and hardness are retained. Stress-tempered low-carbon steels can have strengths comparable with hardened and tempered high-carbon steels, and may be used for springs etc.—K.E.J.

FORGING, STAMPING, DRAWING, AND PRESSING

Recent progress in the field of heavy steel forgings P. G. Bastien (*J. Jun. Inst., Eng.*, 1959, **69,** July, 332–351) The 12th Gustave Canet Lecture. Ingot defects, experimental and vacuum castings, press forging, and heat treatment developments and advances in non-destructive testing are described.

The forging industry: past, present and future G. H. Jackson (*Met. Treatment*, 1959, **26,** May, 191–197) A lecture, concluding a series on forging.

Modern forging manipulators G. Papuli (*Met. Ital.*, 1959, **51,** March, 94–100) The advantages achieved by the mechanization of forging plants using manipulators are examined. After a brief account of the improvements in performance and increase in capacity in the last decade, various types in use are compared and information is given about the big new 120-t forging manipulator installed at Acciaierie della Soc. Terni. Examples of operations carried out by the manipulator are compared with traditional methods.

Gueugnon Forge (*Aciers Fins Spéc.*, 1959, July, 88–93) An illustrated account.

Prospects of establishing a Polish industry producing heavy forgings K. Mogilnicki (*Hutnik*, 1959, (6), 220–222) The article deals on the one hand with the demands in Poland for such products and on the other, with the steps being taken to fulfil these demands. Most of it is devoted to development plans for the next six years.

The fundamental problems of the technology of production of heavy forgings Z. Krzekotowski (*Hutnik*, 1959, (6), 223–237) The author deals with the construction and classification of castings and optimum choice of steel. Further he considers the more detailed problem of heating, hammering, and cooling. Next the production problems of organization are considered and in particular that of delivery. In conclusion, ways of improving methods of manufacture are considered.

Measures against flaking in heavy steel forgings W. Luty (*Hutnik*, 1959, (6), 237–245) The theory of formation of flakes is followed by a discussion of vacuum casting in connexion with the avoiding of flaking. Next preventative hot forging with its advantages is considered as applied in Poland and elsewhere. In particular, work in the 'Stalowa Wola' works is described. Detailed conclusions are drawn.

The yield of hammer forging production and the intended acceptance of the Polish national standard PN/H-94101 Z. Krzekotowski (*Hutnik*, 1959, (6), 245–251) The article considers the effect of forging and machining production on the technological level of the forge. Mention is made of Russian work and that carried out at the Baildon works. Criticism of the Standart PN/H-9401 is discussed followed by consideration of costs of forging and machining production and size of excess metal for machining. In conclusion, Standard GOST 7062–54 is considered as well as a final assessment of standard PN/H-94101.

The effect of sulphur on the mechanical properties of modified forging iron A. S. Suprun (*Lit. Proizv.*, 1959, (1), 13–14) Experiments carried out at the Rostel'mash Works show that contrary to previous concepts no adverse effect is exerted on forging iron, produced by the duplex process and modified with 0·015–0·20%Al during pouring of the metal from the furnace into hot-metal ladles, by a relatively high content of S, but in fact the addition of 0·225%S to the molten iron improved the mechanical properties of specimens annealed simultaneously with ordinary iron. As a result, further experiments were conducted which showed that an increase in S content from 0·105–0·165% slightly decreased the values of the mechanical properties, but a further increase from 0·165–0·215% improved the mechanical properties, by producing a higher proportion of spheroidal graphite. At 0·215%S content the optimum Mn: S ratio was 3·5:2·5. The linear shrinkage of the white modified iron (1·7–1·9) was not reduced by increasing the S content.—M.T.

Technological productivity factors for equipment for die forging C. Gazdaru (*Metallurg. Constr. Masini*, 1959, **11,** (6), 514–518) The problem of efficiency is considered from the point of view of idling time and power consumption of the production processes. Formulae are evolved for the energy needed for the total deformation as a function of the mechanical yield of a hammer blow as related to the drop. The theoretical production time and auxiliary times are also worked out as well as the temperature of the work piece. On the basis of these calculations some suggestions regarding the technology of the processes are proposed.

Temperature: steel forging and tempering colours (*Aciers Fins Spec.*, 1959, July, 111–113) The colours are shown and the uses of colour-sensitive crayons, pyrometers, and thermocouples are mentioned.

The technology of forging and the quality of the metal for steam turbines and turbogenerator rotors N. V. Tikhomirov (*Metallov. Obra. Met.*, 1958, (4), 39–43) Suitable materials are listed and the technology of forging rotors from 5 to 140-t ingots at various plants is described. Suggestions are put forward for avoiding defects and also for rectifying some flaws.

Turbo-Generator rotor forgings made with steels containing vanadium J. Novak (*Hutn. Listy*, 1959, **14,** (5), 436–442) The development heat-treatment, and properties of Ni–V steel containing 0·45%C, 0·50%Mn, 2·0%Ni, and 0·20%V are described.—P.Y.

Automation in forging S. C. Winfield-Smith (*Met. Treatment*, 1959, **26,** June, 231–236) A review of Eumuco equipment with illustrations and diagrams of multi-roller stretching and horizontal forging machines.

Cold reducing tubes on rocking dies D. Robinson (*Canad. Metalw.*, 1959, **22,** June, 20) A brief description of the Micro-Rock process in which two semi-circular grooved dies rock back and forward over the tube compressing it against a mandrel. Reductions of 85% can be made in a single pass.

Measurement of the stresses in welded frames of presses P. V. Novichkov (*Svarochnoe Proizv.*, 1959, **32,** (11), 15–17) Many frames of heavy crank-driven presses are of welded construction. Residual post weld stresses frequently attain the yield point of the material. A complex state of stresses arises which is different for each frame to the same design. Post-weld heat treatment is therefore indispensible.

Efficiency and safety in stamping presses C. Pearson (*Mech. Eng.*, 1959, **81,** June, 65–69) An account of developments at Fisher Body Division of General Motors, with special reference to safety.

Elastic punches for the forming of sheet G. Oehler (*Werkstattstechn.*, 1959, **49,** Jan., 17–22) The author discusses the principles of the various rubber-die techniques and describes tests carried out on small steel and Al parts for the determination of the occurrence of cracks and wrinkles as dependent on a variety of factors.—T.G.

An investigation of tube-expanding practice (1): Effect of clearance on tube-expanding practice of steel tube T. Maruo and H. Ito (*J. Mech. Lab.*, 1959, **13,** July, 155–174) Tables and diagrams in English. The relationships between clearance and total expanding time, total extrusion, hydraulic tightness and holding strength at six different values of clearance using a CB–113 expander tool, which is shown. Total time increases with increase of clearance, total extrusion is unrelated, hydraulic tightness decreases with increased clearance but not directly and there appears to be no relationship to holding strength.

Development of forming processes and the production of forming machines E. Škrabal (*Czech. Heavy Ind.*, 1959, (9), 45–48) Forging presses made in Czechoslovakia are described and illustrated.

Aids to presswork J. Waller (*Mech. World*, 1959, **139,** April, 176–180) Press tool construction, blanking, drawing, and piercing of a bell component, a dual bending tool and the pressing of a special bezel ring are described.

Rationalization of the production of parts by cold shaping H. D. Feldmann (*Werkstattstechn.*, 1959, **49,** Jan., 2–9) The advances made in the last decade in the cold shaping of parts is discussed and the advantages of this process are compared with those of other processes such as sintering, forging, and welding.—T.G.

Chipless turning. A review of the principles and scope of flow forming R. G. Longley (*Weld. Met. Fab.*, 1959, **27,** June, 229–233, 252) One of the principal uses of flow turning is in making thin walled parts of conical or cylindrical form although other contours are now possible. Modern machines have brought considerable refinement to the process.—D.L.C.P.

Floturning moves to a new market (*Steel*, 1959, **144,** May 25, 150) In the example of the process cited a flat blank is formed into a cone which is then shaped into a cylindrical tube up to three diameters long. The process is expected to compete with normal drawing techniques.—A.G.

Aluminium and steel fabrications for nuclear plant (*Mech. World*, 1959, **139,** April, 181–182) Fairey Aviation Co. methods are briefly described.

This part is hardened with explosives (*Steel*, 1959, **144,** May 4, 84–85) Explosive sheet has been used to harden Hadfield steel parts, increasing the Brinell hardness by 300 points. Applications are mainly in railway, construction, and mining equipment.—A.G.

Methods used in the drawing of irregular steel sections of high precision F. Boehm (*Werkstattstechn.*, 1959, **49,** Jan., 26–31) The author describes the profile-drawing process in which steel sections of irregular shapes are produced. Difficult profiles require hot-rolled blanks which are then cold drawn, but most profiles can be made from commercial sections. Blanks and dies must be carefully calculated as reduction in area per pass is limited an stretching must be uniform across the section. Some practical recommendations are included.

Drawn special carbon and alloy steels (*Aciers Fins Spéc.*, 1959, July, 22–24) The scouring and drawing of steel bars, dies, tolerances, heat treatment and dressing are briefly indicated.

A definition of the length of the cylindrical part of the floating roll mandrel in pipe drawing H. Orzechowski (*Hutnik*, 1959, (4), 158–160) The author outlines the advantages of this method where the tube is pulled through a die. He then develops a mathematical expression for the length of the cylindrical part of the mandrel.

Works trials on power requirements in the push bench tube making process A. Geleji, E. Kiss, and G. Dévényi (*Acta Techn.*, 1958, **22,** (3–4), 395–412) [In German] Piercing power and rate in the piercer press and power, speed, and the output of the drives of the push bench were measured. Power measurements were made with strain gauges and recorded on oscillographs. The results are discussed, and compared with values calculated on the basis of the theory developed by Geleji. Full experimental details are given.

Automatic line processes bars at high speed (*Iron Steel Eng.*, 1959, **36,** May, 156–159) A completely automatic high speed line for the continuous cold drawing, straightening, cutting, and polishing of bar from coiled rod is described. The machine, built by Loma Machine Manufacturing Co. has a speed of 200 ft/min.

The introduction of high drawing speeds in wire drawing shops for steel wire S. Hájek (*Hutnik*, 1958, **8,** (1), 15–20) [In Czech] Wire drawing speeds as used in Czechoslovakia are lower than averages of best foreign practice. Improvements in raw material quality, technology, and machine design, which could contribute to remedying this situation, are discussed.—P.F.

Manufacture of rivetting wire from 30KhGSA alloy steel Ya. Kh. Sartan (*Metallurg*, 1959, (2), 32–33) A description of the process is given: descaling and pickling the wire rod, drawing of blanks, heat treatment, pickling, calibration, testing in conformity with the technical control requirements, packing, and storing. This wire is much used in the aviation industry.

A versatile American rod and wire mill (*Wire Ind.*, 1959, **26,** March, 267–270) The installation described is at the Aliquippa works of Jones and Laughlin and comprises a three-stand rod mill together with wire drawing equipment which can produce material from 0·006 to 1 in. in dia.—A.G.

Apparatus for ramming rods into draw plates G. M. Fomin (*Metallurg*, 1959, (3), 33–34) A plan is given of a new apparatus for ramming a non-sharpened rod into a draw plate, for which a number of advantages are claimed; no need for extra electrical or hydraulic drive, the rod can be drawn into two strands; simplicity, compactness, and cheapness of construction.

Efficiency of steel ropes B. M. Vorontsov (*Metallurg*, 1959, (3), 34–35) A new method of twisting steel ropes where the rows of strands are built up in linear contact while the angle of twist in all concentric rows remains uniform. Ropes built up in linear contact can only be made of different diameters of strands. Each row of wire fits into the channel formed by the wires of the preceding row.

Progress in cold extrusion of steel (*Sheet Met. Ind.*, 1959, **36,** May, 353–358, 366) A description of the development work and practice at the Royal Ordnance Factory, Birtley, is given. Two instances of the production of shells using cold extrusion stages are given. Work is also in hand on producing gear-type parts.—D.L.C.P.

Tool steel pressure limits hiked for impact extrusions (*Western Metalw.*, 1959, **17,** May, 40–41) By exerting three times the pressure specified for tool steel, cold alloy steel can be successfully formed by impact extrusion. The importance of lubrication between each forming stage is stressed.—A.G.

Use of extruded steel profiles H. Eckardt (*Acier-Stahl-Steel*, 1959, **24,** Nov., 499–505) Sections are shown and their uses are discussed.

ROLLING MILL PRACTICE

Deformation of the work material in cross rolling M. Ya. Brovman (**Stal'*, *Rolling and Tube Manuf. Supp.*, 1959, 22–23) A method of calculation is presented and a condition for critical reduction producing axial cavity-formation is arrived at. The values are close to those obtained by Smirnov's method and also correspond with measured values.

Measurement and analysis of the rolling process on a 750 mm dia. rolling mill S. Bala, J. Jonca, and J. Rabalski (*Hutnik*, 1958, **25,** (10), 390–396) Measurements were made of rolling pressures and other parameters of the rolling process which were then analysed. The experiments show that the pass design of the rolling mill under investigation was incorrect. Reduction of the rolling temperature by 100°C caused an appreciable rise in pressure, especially when rolling high-carbon steel. The three-high stand has four passes at each level in 750 mm dia. rolls (body length 2 150 mm) with lifting tables on each side of the stand and an edging manipulator and guides only on the delivery side. Fracture of the rolls, in the light of the experiments, is attributed to faulty roll pass design, inadequate strength of the rolls of to uneven heating of the ingots. It is recommended that in view of the difficulty of using any type of pyrometer, pressure should be the criterion, this is a function of temperature. The value of such investigations cannot be underrated.—M.T.

Rolling torque and output A. Geleji (*Acta Techn.*, 1959, **24,** (3–4), 447–460) Rolling torque is calculated on the assumptions that (a) pressure distribution is uniform on the compressed surfaces and (b) resistance to deformation along these surfaces is distributed non-uniformly.

Rolling problems Z. Wusatowski (*Hutnik*, 1959, **26,** (7–8), 289–296) The author discusses fully the main postulates of the theory of rolling as set out by J. M. Pavlov. The author maintains that his and his co-workers test results did not agree with these. A detailed description of what has been done, assumptions and results are given and the author maintains that at present it is impossible to formulate a theory of rolling on simplified assumptions as was done by Pavlov.

Grooving rolls for a piercing mill with a minimum entry cone angle V. Ya. Ostrenko, P. I. Batutin, E. I. Ulinskaya, and N. S. Kirvalidze (*Metallurg*, 1959, (4), 30–31) The piercing mill at the Southern Tube Works was fitted in 1957 with new grooved rolls with a minimum entry cone angle of 1° instead of the 3°30′ previously used. Results show many advantages of the new rolls, for example, power required for piercing blanks with an angle of 1° is less by 3·5% and power expenditure less by 26% in comparison with rolls having an angle of 3°30′.

Indirect measurement of loading during rolling R. Hagel, J. Jońca, and Z. Kazior (*Prace Inst. Hutn.*, 1959, (1), 25–31) In introduction the authors give the reasons for undertaking the construction of an instrument for this purpose. Next follow the choice of a method of measurement, its theory, its sensitivity, a description of construction, and method of use, and finally a description of tests carried out and errors observed. It was found that the method using the elongation of the rolling mill stand column gave a roller load accuracy of about ±10%.

Load-cells for measuring large roller loads J. Jońca and J. Rabalski (*Prace Inst. Hutn.*, 1959, (1), 33–40) After due consideration of various methods the strain gauge method is chosen where the gauges are cemented in a mutually perpendicular arrangement and connected to a bridge-circuit. Both ac and dc measurements are possible. In the case of dc no amplification is necessary. A prototype was described for pressures up to 500 t which was modified after tests to deal with loads from 10 to 1 300 t. The ac and dc cells were found to have accuracies of ±2% and 1·5% respectively.

Roll force and torque during the hot rolling of low-carbon steels with high draughts Z. Wusatowski and B. Hoderny (*Arch. Hutn.*, 1959, **4,** (2), 161–180) Steel with 0·19%C, 0·31%Mn, and 0·1%Si was used on sections 40×40, 20×40, 20×100, 15×100, 10×100, and 10×110 mm and heated to 900 1 000, 1 100, and 1 200°C and rolled with draughts of 50, 60, 70, 80, and 90%. Loads and torques were measured and curves are plotted for the various conditions and temperatures.

Secondary conditions of axial engagement in oblique rolling P. K. Teterin (**Stal'*, *Rolling and Tube Manufacture Supp.*, 1959, 133–138) Conditions are derived for some of the secondary conditions of axial engagement where the axial resistance of the plug is taken into account. To avoid cavitation in the centre of the billet ahead of the plug and flaws in the hollows produced, minimum reduction ahead of the plug is applied. Two formulae for the reduction are quoted and neither takes into account coefficient of friction, roll diameter or feed angle. A new expression is derived and practical consequences are deduced.

Built-up steel rolls for a heavy plate mill and the causes of their withdrawal from service M. A. Zadorozhnaya, P. Ya. Ryshkov, and L. A. Volkova (*Metallurg*, 1959, (9), 29–31) The three-high Lauth plate mill at the Petrovsk plant has cast iron top and middle rolls and the bottom steel roll is built up. This roll 910 mm in dia. and 3 m long is automatically built up under a flux layer. It is first mechanically treated and all surface defects are removed. The dia. of the machined roll is minimum 875 mm at the centre and 870 mm at the end, and any hidden cracks are found with an ultrasonic defectoscope type UZD–7N. The roll is then built up with electrode wire EI 701 4 mm dia. under a layer of AN–20 flux.

Delayed failure of rims of the cold-rolling backing-up rolls M. M. Kobrin and K. V. Shishokina (*Metallov. Obra. Met.*, 1958, (5), 43–48) Rims of 2 m length, 1·6 m outer and

0·8 inner diameter are made of 0·85%C and 1·6%Cr steel. The tendency to delayed failure develops in 9Kh steel both under short and long periods of stress applications. This tendency to failure and to brittleness is attributed to tempering at 400°. Surface hardening, on the contrary, eliminates the tendency to delayed failure, increases hardness and wear resistance of the rolling surface, and promotes a high plasticity of the metal.

Hydrodynamic bearings for rolling mills—the Morgoil W. R. Pigott (*Anvil*, 1959, **5**, Summer, 10–14) An illustrated description.

Recent developments in roll neck bearing design and mounting E. C. Denne jun. (*Iron Steel Eng.*, 1959, **36**, May, 117–126) The design of the multi-row cylindrical roll neck mounting and its fitting and operation are described, and recent modifications are indicated.

Report of an enquiry into blooming and slabbing mills, May to September 1957. Part I. Electrical drives of blooming and slabbing mills C. Roger (*Centre Doc. Sidér. Circ.*, 1959, **15**, (11), 2263–2288) Resulting from an enquiry made at a number of works, this report describes and compares the circuits and characteristics of the blooming and slabbing mill drives, the data obtained are classified and tabulated (17 refs).

Improving the grooving for a blooming mill L. V. Andreyuk and M. I. Igon'kin (*Metallurg*, 1959, (4), 23–24) Some blooming mills at the Magnitogorsk plant consist of reversing-type two-high stands rolling 250 and 290 mm square blooms and 135 to 190×530 to 850 slabs. The rolls have the first groove in the centre. Construction of the roll and the special grooving is given.

Optimum rolling schedule for ingots in a blooming mill L. V. Andreyuk (*Stal'*, 1959, (9), 817–820) A design of 11 passes was found to overload the mill causing breakdowns which are discussed. A new schedule of 13 passes was substituted with smaller reductions. A mean reduction per pass of 65–75 mm, bite angles not exceeding 20–22° with plain and 23–24° with grooved rolls, edging at every fourth pass, acceleration and deceleration of the drive motor at 50–70 revs/min/sec and biting of the ingot in all passes at maximum roll velocity.

Operation of an 850/730/530 continuous billet mill with vertical stands in the Chinese Peoples' Republic I. F. Belobro, I. G. Bukhvostov and A. E. Milikhin (*Stal'*, 1959, (9), 812–817) A description of the mill and its erection, equipment, and rolling program is given and of the roll pass designs and running in.

Do not repeat mistakes when planning new rolling jills S. M. Nosenko (*Metallurg*, 1959, (10), 1–3) Not enough attention has been paid to the matter of profiting by past mistakes in rolling mill designs in the Soviet Union. As a result of four years operation of a 46 in. blooming and slabbing mill at Alchevsk, many design defects came to light which will now be eliminated in the new rebuilding. Some of these defects were allowed to reappear in the recently constructed blooming mills at Cheropovets and Krivoi Rog. Among matters discussed are adequate crane capacity for soakers and runner tables, efficient reception and removal of crop ends by means of large capacity railway 'platform boxes'. The latter are being installed in the new blooming mill at Alchevsk. Other matters are the removal of mill-scale, multi-position cut-off and stamping machines for blooms and billets, automatic deseaming, automatic determination of the extent of pipe in the rolled product, so that it can be completely eliminated, automatic weighing of ingots passing to the blooming mill, automatic fixing of the actual thickness, width, and length of rolled products and the transfer of this information to the shears so as to rationalize the cutting length, development of a system of granulating slag in the croaking pits so as to avoid the difficulty of handling large monolithic slag masses.—R.S.

U.S. Steel expands at facilities Vandergrift (*Iron Steel Eng.*, 1959, **36**, July, 175–176) Modernization and expansion of the facilities for stainless steel sheet finishing at Vandergrift are described. These include a Sendzimir mill and ancillary equipment.

Changing the grooving for section No.4 for punching out M. B. Shuralev and S. G. Nekrasov (*Metallurg*, 1959, (3), 26–27) A new grooving method is suggested which would require 8–10 passes instead of the old method with 6–12 passes for the production of this section, which is much used in the manufacture of cutting tools.

Rolling angle steel with a transfer apparatus V. K. Yatsura (*Metallurg*, 1959, (6), 26–30) A transfer apparatus for small sections was introduced in 1955 at the MMK works. In 1956 the Dzerzhinsk plant experimented with transfer apparatus for angle steel with rollers with a tilting angle of 40–45°. This apparatus is covered by patent certificate 112206 of 13/III/57 where it is fully described with drawings and measurements.

New giant roller takes on heavier plate capacities (*Iron Age*, 1959, **184**, July 9, 92) The 40-t pinch-type roller described can exert a 2500-t bending pressure. Plates 4 in. thick can be formed into cylindrical shapes.—A.G.

Flat-rolled steel: development as a structural element G. Frank (*Met. Treatment*, 1959, **26**, July–Aug., 284–288; from *Lehren und Leisten*, (2058), 271) The replacement of angles and other sections by elements fabricated from sheet is discussed. Examples of the forms produced, brittle varnish testing, and stressed skin constructions are dealt with.

Thickness gauges for heavy sheet rolling mills and for roughing trains of strip mills (*Centre Doc. Sidér. Circ.*, 1958, **15**, (10), 2117–2122) A description of the principle and operation of two types of thickness gauge developed by Davy United in cooperation with Isotopes Development Ltd of Harwell and BISRA respectively is given.

Production of cold rolled dynamo steel V. Kh. Faizullin (*Metallurg*, 1959, (10), 21–25) Cold-rolled dynamo steel analysed C 0·04–0·06, Mn 0·25–0·40, Si 1·2 to 2·0, S 0·025 max., P 0·03 max., Cr 0·05 max., Ni 0·05% max. Details of production sizes for slabs and sheet up to 30 in. wide are given. Heating and rolling practice are described in detail and the effect of heat treatment on the magnetic properties is discussed.—R.S.

The problem of steel rolling in Latin America E. de Macedo Soares e Silva (*Problemas de la Industria Siderurgica y de Transformacion de hierro y acero en America Latina*, 1957, **2**, 132–136) Problems of steel rolling in relation to conditions existing in Latin America are outlined, various types of rolled product being dealt with **Selection of primary rolling equipment as a function of the growth of markets in Latin America** K. Schlesinger (136–149) A detailed discussion, with examples, is given of the types of primary rolling equipment suitable for various sizes and types of production units. **Selection of equipment for rolling flat products as a function of the growth of the market in Latin America** W. F. Cartwright and M. F. Dowding (149–166) A detailed account of the selection of rolling equipment for various qualities and sizes of strip and tin plate, the economics of the equipment being considered. **Selection of equipment for rolling bar and sections: in relation to the Latin American market** E. Wilms and E. Krebs (166–173) Several typical cases related to various annual production figures are stated and discussed. **Extension and modernisation of the rolling mill trains of the Cia Fundidora de Fierro y Acero de Monterrey, S.A.** R. Barragán (188–192) An account of the modernization of the rolling mill plant is given, together with an outline of the extension of the blast-furnace, steelmaking, and reheating capacity of the works. **Rolling problems of a semi-integrated iron and steelmaking plant in Latin America** M. Sherover and W. P. Lewicki (193–199). **Description and field of application of Sendzimir Mills** M. G. Sendzimir (207–213) The construction of the Sendzimir mill is described and its applications and advantages are discussed. **Description of a Brazilian rolling mill for high-grade steels** L. D. Villares (240–243).

Critical reduction of dynamo steel B. F. Trakhtenberg (*Metallov. Obra. Met.*, 1959, (5), 24–28) The critical range corresponds to a reduction of 4–8%. This is shown to be due solely to grain growth. Studies on magnetic and rolling properties, especially in this range, are reported.

The influence of final rolling temperature on the properties of St 3 sp steel plates I. D. Kuzema (*Stal'*, 1959, (8), 745–747) The steel, for ship plate, has 0·14–0·18%C and S and P < 0·04% to meet specification ChMTU 5678–56. Attempts to meet this in the as-rolled condition were made and impact strength was measured at −40°C. Ingots were rolled at final temp. of 1050, 950, 900, and 850°C and cooled on the roller table and the optimum range was 850–900°C. For minimum 3 kg/cm² impact strength at −40°C, Al and Ti-killed specimens were rolled at 10, 15, and 20% deformation per pass and satisfactory final rolling conditions are given.

Metalworking processes and equipment A. G. Thompson (*Weld. Met. Fabr.*, 1959, **27**, May, 210–213) Various cone rolling and plate bending machines are described.

Hoesch broad strip mill (*Engineer*, 1959, **207**, April, 598–550) An illustrated account of the Dortmund mill rolling strip up to 1600 mm wide with a monthly capacity of 44000 metric tons which could be quadrupled if necessary. A blast-furnace gas heated pusher furnace is used and special precautions against mining subsidence were taken.

Roll-temperature measurement in a strip mill R. Hirschfelder (*Stahl Eisen*, 1959, **79**, Aug. 6, 1144–1145) The technique of measuring the temperature of water-cooled rolls of a strip mill and the difficulties involved in these measurements are described and the results obtained at the first and the sixth stand discussed briefly. The peak temperatures measured were about 120°C.—T.G.

Use of a width-gauge on continuous hot-rolled strip Giry (*Centre Doc. Sidér. Circ.*, 1958, (7), 1505–1509) A description of the apparatus, including main characteristics and operation, is given. The width-gauge eliminates the disadvantages of time-loss and lack of precision inherent in the older methods. The exact width is indicated at all times, and the precision was found to be ±2 mm for strips between 650–1550 mm wide.—A.M.A.M.

Control of sheet thickness in a continuous wide-strip rolling mill Giry (*Centre Doc. Sidér. Circ.*, 1958, (7), 1487–1504) Disadvantages of control by manual measurement with a micrometer are outlined, and the attainable degree of precision analysed statistically. The working principles, construction, use, calibration, tolerance, and maintenance of an automatic thickness, controlling X-ray gauge (Sheffield model 50-HM-100, serial No.10), are extensively described. A study of results shows manifestly the advantages of the latter, for example in instantaneous correction of thickness, and knowledge of the exact cross-section of the strip at any instant.—A.M.A.M.

Study on the rolling of metals and alloys with Sendzimir reversing cold strip mill. I. Pattern of waves appearing on the metal foils E. Tanaka and T. Yoshiki (*Sci. Rep. Res. Inst. Tohoku Univ.*, 1958, **A10**, Dec., 405–413) [In English] On a mill of the ZR 32–4 type, the strip surface sometimes showed regularly spaced waves inclined to the rolling direction. The occurrence depended on the front tension, and there was no change in structure of the strip. The waves are a type of centre buckling, but are not stretcher strains or herringbone markings.

Radiation gages control Sendzimir mill (*Steel*, 1959, **144**, April 27, 108) A gauge is described which measures thickness by beta or gamma radiation. Signals from the gauge operate a servo-system which continuously changes screwdown setting. Output is said to be regulated to within ±1% of the specified thickness.—A.G.

Automatic machine controls at the Brinsworth mill of Steel, Peech & Tozer A. P. Baines (*English Electric J.*, 1959, **16**, March, 42–50) A detailed account of the control system for the hot strip mill is given.

Cold rolled steel sheets produced at Osaka Works K. Nakamura (*Nihon Teppan*, 1959, **10**, March, 29–35) The discussion includes stretcher strains, temper rolling, 'orange-peel' effects, pipe, mechanical properties, and surface finish.—K.E.J.

Control of the cold rolling process J. D. Heys (*Sheet Metal Ind.*, 1959, **36**, April, 281–297,

299) A review, one of the series of papers at Wolverhampton and Staffordshire College of Technology on the correlation of rolling theory with practice. Metal structure, gauges, and automatic control methods are described.

Cold rolling mills for narrow- and medium-strip C. Volkhausen (**Blech*, 1957, Nov., 88–92, translated into Spanish).

Drive systems for high speed tandem wire flattening mills P. S. Hasler and R. D. Spalding (*Wire Wire Prod.*, 1959, **34**, April, 437–442, 495) A modern wire flattening mill system is described with emphasis on the electric drive and the application of automation.—A. G.

Couplings for rolling mill drives K. Breuer (*Demag Nachr.*, 1959, (155), 20–25) The main functions of these couplings are enumerated, and various types described with references to those functions.

Tooth face damage and bearing capacity of rolling mill gears M. Unterberger (*Stahl Eisen*, 1959, **79**, Sept. 3, 1268–1273) A study of the failures of rolling mill gears showed that even today the various manufacturers of such gears work on entirely different fundamentals. Failure of the tooth faces must be expected owing to the extremely high loading that occurs temporarily in rolling practice. Failure is usually in the form of pitting caused by local overloading in conjunction with lack of lubrication. The use of additives to the lubrication oils is advised, whereas higher viscosity rarely prevents pitting.—T. G.

Mechanised billet shears device reduces accidents (*Safety*, 1959, May, 28–29) Mostly illustrations.

Rolling faults and their effect on the quality of steel wire Z. Steininger (*Hutnik*, 1958, **25**, (9), 340–346) A review is made of the commonest faults occurring during rolling, viz. eccentric and distorted sections, shrinkage cavities, impurities and non-metallic inclusions, surface faults, such as laps and decarburized layers, and other faults. The faults are described and illustrated with microstructures etc.—M. T.

The regeneration of scale and water in the rolling mill J. Tůma (*Hutnik*, 1959, **9**, (5), 166–169) Economic and technological aspects of the regeneration of rolling mill scale and of the water carrying it are discussed. It is shown that the problem can be solved in principle, but that further work is required to find ways for degreasing the contaminated water as well as the scale.—P. F.

Punched-card control equipment for rolling mills H. Cordes (*Stahl Eisen*, 1959, **79**, Aug. 20, 1218–1220) The principles, merits, and shortcomings of the automatic control effected by a punched card system are explained on the basis of published information. The main advantages offered by the automatic system are somewhat limited by the rigidity of the programming, i.e. only a very limited variety of products can be produced by this means; in other words it is suited only for large production lines for the same product. Magnet drums are suggested as more suitable for mills that roll a variety of products, but the capital cost of such equipment is considerably higher.

Safety and health of rolling mill operators as a factor in increasing the output of mills M. Bielanski (*Hutnik*, 1958, **25**, (11–12), 486–491) On the basis of the analysis of the factors adversely affecting the work and efficiency of mill operators, it is possible to improve their efficiency and at the same time increase the output of mills, and so the outlay on safety and health measures may be regarded as an economic investment. The factors considered are the effects of high ambient temperatures and radiation, noise, impact shocks, and vibrations, visibility and body position, illumination, cleanliness and tidiness of the plant, and measures for their mitigation are suggested.

WELDING AND FLAME CUTTING

Introduction to modern welding methods F. Zubeldia (*Cien. Tecn. Solda*,. 1959, **9**, March–April, 6, 60, 1–7) A brief review of the principal features of a number of modern welding procedures; a descriptive treatment to introduce a series of practical articles on welding technique.

Forty years of welding (E. Coupland and R. S. Pickering (*Weld. Met. Febr.*, 1959, **27**, May, 214–216) An account of the development of techniques by Rubery, Owen & Co., since 1920.

Welding of grey cast-iron in Rumania T. Sálágean (*Zváranie*, 1959, **8**, (5), 140–142) [In Slovak] A new method of joining cast iron by flash welding is described. The abutting ends to be joined are rapidly pre-heated and momentarily melted just prior to being pushed together without appreciable pressure. The bend strength of the joint is equal to 80% of the plain metal.—P. F.

Remarks on recent developments in arc welding processes A. Gaubert (*Soud. Techn. Connexes*, 1959, **13**, March/April, 85–98) Eight types of welding methods are examined critically. Particular reference is made to semi-automatic welding of mild and low-alloy steels. Requirements to be met are discussed in relation to selection of methods and materials. Welding in an atmosphere of CO_2 and electroslag welding are commented on.—R. P.

Welding of medium-alloy chrome moly steels K. R. Notvest (*Welding J.*, 1959, **38**, May, 222s–227s) Forged and cast 5%Cr 0·5%Mo steels were investigated, to throw light on problems encountered in welding crack-sensitive alloy steels. It is concluded that in general preheats of 450°F or higher should be used for first pass and manual welding, or 400°F where higher interpass temperatures are anticipated. Low C and low H_2 covered electrodes should be used, and other conditions are specified to ensure sound welds by economic methods (15 refs).

High-frequency resistance welding in the metallurgical industry B. Vostrý (*Hutnik*, 1959, **9**, (7), 238–240) Theoretical and practical aspects of the method are discussed, and its versatility and rapidity are pointed out. These properties presage a rising popularity of high frequency resistance welding in the metallurgical and other industries.—P. F.

Maintenance applications of welding R. J. Osborn (*Iron Steel Eng.*, 1959, **36**, Sept., 107–116) Examples are described and illustrated relating to rolling mill maintenance carried out by thermit or arc welding.

Submerged arc-welding in the production of thin-walled pressure vessels J. Švercl and S. Vysloužil (*Zvaranie*, 1959, **8**, (6), 179–181) The technology of welding pressure sheet steel vessels for waterworks, as developed in the Sigma Works in Czechoslovakia, is described.

Thermit welding structural mill rolls E. B. Russell (*Iron Steel Eng.*, 1959, **36**, June, 123–131) A general description of thermit welding techniques is followed by details of its application to the repair of structural mill rolls.

Strong welds at brazing temperatures (*Metalw. Prod.*, 1959, **103**, April 3, 583–586) The low heat input technique of welding, using eutectic composition welding alloys is described with examples.

Submerged-arc welding on the pipe line W. B. Handwerk (*Weld. J.*, 1959, **38**, July, 672–675) Pipe of min. dia. 22 in. is welded into double lengths before being built into the pipeline, thus increasing building speed. Submerged arc welding is used, and the whole process of handling and welding is done automatically, with the exception of one 2-in. tack weld during lining-up, and tracking the welding carriage. External and internal welds are made.—K. E. J.

Cyclic welding method salvages heavy mill equipment R. L. Rectenwald (*Iron Steel Eng.*, 1959, **36**, Sept., 117–125) The 'cyclic' welding of hypereutectoid steels, i.e. welding at controlled cooling rates, with continuous and repeated stress relief is discussed with examples. Mass of weld metal deposited, thickness of parts joined and alloy composition of the parent metal are considered to be unlimited.

Application and safety of welded joints in new structures and repairs E. Folkhard (*Schweiz. Arch. Wiss. Techn.*, 1958, **24**, Dec., 412–419) Electric arc welding of steel is discussed from the point of view of changes of the parent metal due to the welding process, suitability of electrodes and the behaviour of the welded joint. Examples of failures in the weld area are discussed in relation to cooling rates, composition, and properties. Conclusions drawn can be applied to other welding methods in a general manner.—R. P.

On the welding of various austenitic stainless steel tubes J. Omori and H. Maruoka (*Sumi. Met.*, 1959, **11**, Jan, 22–36) Tests of arc and inert-gas welds on 18–8 and 18 Cr–8 Ni–Mo, –Nb and –Ti steels are reported. The room-temp. properties were good. In high-temp. tensile tests the fracture was on the base metal. The lowering of impact value on ageing is more severe in the weld than the heat-affected zone. Corrosion resistance of the joint is affected by subsequent heat-treatment, but only slightly with the Nb– and Mo-containing steels.

Welding of longitudinal joints in large diameter pipes with high-frequency resistance heating N. P. Glukhanov, V. N. Bogdanov, and V. L. Kulzhinskii (*Svarochnoe Proizv.*, 1959, (2), 6–8) A description is given of experiments in welding longitudinal joints in 12 m long tubes of dia. 529–1020 mm by heating the edges with h-f currents and applying pressure on reaching the necessary welding temperature. The optimum parameters were: heating time 15–20 sec; heating temperature 1350–1400°C; specific upsetting force 4–5 kg/mm²; extent of upset 6–8 mm. A force of 1–1·5 kg/mm² was applied during heating. After normalization (again with h-f currents) at 900–1000°C the weld metal was of the original fine grain structure, and there was a marked improvement in the mech. props., with impact strength 6–10 kg m/cm² and bending angle 150–180°. Slag is formed both internally and externally and must be removed. On pipes with wall thicknesses of 8–10 mm at the above parameters a specific voltage of 200 kV per m length of pipe is adequate. The method is now being used for production at the Chelyabinsk Tube Works.

Friction welding as a method of repair of worn components Kh. A. Tyayar (*Svarochnoe Proizv.*, 1959, **32**, (10), 23–24) Examples are given of the application of the method to the repair of steel components.—M. T.

The use of welding and kindred processes in the maintenance and repair shops of railroad rolling-stock J. Dairier (*Rev. Soud.*, 1959, **15**, (3), 136–146) The author describes the use and testing of welding in repair of steam, diesel, and electric locomotives and rolling-stock and their components, giving details of organization, with two graphs showing increase of personnel 1951–58.—S. H.–S.

Power and heating during friction welding of thick-walled steel tubes A. S. Gel'man and M. P. Sander (*Svarochnoe Proizv.*, 1959, **32**, (10), 18–20) With the increase in temperature the coefficient of friction first of all rises rapidly and then falls gradually; an increase in linear velocity and specific pressure leads to a reduction in the friction coefficient, and the power required for heating by friction changes accordingly. The initial pressure should be low (1 kg/mm²), but after reaching the peak output point it should be increased to five or six times this value. Indications are given of methods of calculating the power required to generate adequate heat for welding by friction.—M. T.

Fabrication and construction of the piping system for the Dresden Nuclear Power Station G. B. Grable and A. M. Croswell (*Weld. J.*, 1959, **38**, July, 657–664) The primary loop of the reactor operates at 1000 psig and 500°C, and its piping consists of type 304 Cr–Ni austenitic stainless steel, in various diameters up to 22 in. Details are given of the fabrication of various items for this loop, and of off- and on-site welding; the submerged arc, inert-gas, and tungsten arc and manual shielded metal arc processes were used.—K. E. J.

Power required during friction welding of steel rods V. I. Vill' (*Svarochnoe Proizv.*, 1959, **32**, (10), 12–15) The third stage during friction welding is decisive for the quantity of heat liberated. In order to increase heat output during friction welding, no attempt should be made to increase the rate of rotation and under given circumstances there is an optimum rate of rotation. A great influence is exerted on duration and sequence of the process by the initial state of the surfaces to be welded. To produce the maximum heat output from the frictional forces, a slow and gradual growth in

applied axial stress is required. Experiments were conducted on 8–50 mm dia. carbon steel rods at rates of rotation of 240–3000 revs/min and a specific pressure of 2–10 kg/mm^2.—M.T.

Automatic welding under ceramic flux of steel resistant to cold brittleness K. K. Khrenov M. N. Gapchenko, and D. M. Kushnerev (*Avtom. Svarka*, 1958, (12), 50–56) For 12 N3 steel it was established that at −160° the resistance to cold brittleness of welds made with CV–08A low-carbon wire is greater if the welding is done under a ceramic flux, which ensures a chemical composition near to that of the base metal. The joint must be subjected to subsequent heat treatment. The flux consists of marble, fluorspar, and titanium dioxide.

The development of the technique of, and equipment for, welding non-rotatable joints in large diameter pipes A. S. Fal'kevich and Yu. I. Marchenko (*Svarochnoe Proizv.*, 1959, (2), 8–12) The article is devoted to experiments with CO_2 arc welding of such pipes and the development of equipment for field work. The following parameters were used: welding current 110–160 A; arc voltage 19–21 V; amplitude of transverse vibrations of electrode 2–5 (first weld bead), 14–18 (second weld bead); welding rate 3–11 m/h. Two welding heads were used simultaneously. Satisfactory welds were obtained with good mechanical properties, and the method is under further development.

The effect of the chemical composition of austenitic 25-20 weld metal on the gamma-sigma transformation B. I. Medovar and Yu. B. Malevsky (*Svarochnoe Proizvodstvo*, 1959, **32**, (4), 12–16) Experiments were conducted on submerged-arc welded plate specimens 12 mm thick using dc reverse polarity with isothermal heat treatment at 650, 800, 875, and 900°C for 25 up to $3\text{–}8\times10^3$ h, in some cases after peening with 30% expansion, to study the effect of Mn, Mo, and W. Mn did not increase the tendency to sigmatization, but Mo and W and peening, especially with treatment at 650 and 800°C, did so markedly. A reduction in the Cr content of the weld metal from 22–25% to 20–21% at Ni contents of 15–25% sharply reduces embrittlement at high temperatures. An increase in the C content from 0·10 to 0·20% suppresses the γ–σ transformation in the weld metal, but ageing of such metal reduces the impact strength through secondary carbide precipitation. N_2 inhibits sigmatization by formation of CrN.—M.T.

An investigation of carbon distribution in the weld fusion and heat-affected zones K. V. Lyubavsky and M. A. Studnits (*Svarochnoe Proizvodstvo*, 1959, **32**, (4), 7–11) A study was made of carbon migration by diffusion from the base metal (austenitic tube steel) to the weld metal by the introduction of ^{14}C into the base metal The welding process gave rise to no such migration but stabilization at 800°C for 20 h and or ageing at 580–600°C for 1000 h produced varying degrees of migration and impoverishment of the base metal, with resultant cracking of the heat-affected zone. This migration is to a large extent due to differences in the contents of the carbide-forming elements in the base metal and weld metal.—M.T.

X-Ray control of welded steel joints R. Gabrovski and A. Bancila (*Met. Constr. Masini*, 1958, *Vienna welding congress supplement*, 34–42 [In French] A summary of the methods and an appreciation of the results.

Special features of the modification of welded joints with titanium during the welding of medium carbon steel K. K. Khrenov, L. A. Poznyak, Yu. A. Yuzbenko, and M. S. Samotryasov (*Svarochnoe Proizvodstvo*, 1959, **32**, (6), 6–8) Experiments to study the modifying action of Ti on steel containing about 0·5%C, by (*a*) its introduction into the weld pool through the electrode wire or (*b*) through ceramic fluxes, showed that (*b*) is twice as effective as (*a*) to produce an equiaxial structure and only at low added Ti contents is the grain refinement accompanied by a simultaneous increase in the plastic properties and absence of cracking. The method of introduction of the modifying element must avoid overheating and deactivation of Ti (e.g. by passing through the centre of the arc gap). This is avoided by method (*b*), in conjunction with which the welded joint should contain 0·008–0·018%Ti. Method (*a*) is only a means of avoiding crack formation, where a marked reduction in plastic properties is unimportant and necessitates an addition of about 0·5%Ti to the joint.—M.T.

Experience in the prevention of crack formation in fillet welds in low-alloy steels G. V. Nazarov (*Svarochnoe Proizvodstvo*, 1959, **32**, (5), 36–37) Hot cracking occurs at 0·12%C content of the weld metal, but may be prevented by a reduction to 0·08–0·12%C. The first layers should consist of two beads at lower parameters with a 2 mm dia. wire, while subsequent layers may be made with a 5 mm dia. wire at higher parameters.—M.T.

The effect of porosity on the fatigue strength of welds G. Kullberg (*Svetsen*, 1959, **18**, (3), 54–56) Experiments conducted on the fatigue of welds in steel of composition 0·08%C, 0·13%Si, 0·65%Mn, 0·015%P, 0·017%S, 0·008%N show that X-ray examination which reveals no actual cracks but the presence of very slight porosity does not indicate the operational risk involved, since it is impossible to tell whether the porosity will rapidly develop into a crack. Their behaviour was found to be very varied. X-ray methods should not therefore be wholly relied upon.—M.T.

Effect of structure of flux on porosity of welds V. V. Podgaetskii and A. V. Mel'nik (*Avtom Svarka*, 1955, (4), 58–62) Porosity of welds made under a foam-like flux was less than under a vitreous flux of similar composition. Fluxes with high CaF_2 and SiO_2 content appeared to form SiF_4 and so minimize the effect of rust. The greater surface of the foamed fluxes apparently made them more effective.

Welding cracks in the heat affected zone of air hardening alloy steel H. Sekiguchi and T. Kobayashi (*Lastechnick*, 1959, **25**, July, 142–146) [In English] Four types of base metal cracks were found in transverse and longitudinal sections of small rectangular samples of NiCrMo steel to which a weld deposit had been applied. These involved toe, underbead, transverse, and longitudinal cracks and from the frequency of their occurrence under various welding conditions, it seems that H_2 is only of importance in causing underbead cracks. The time factor between welding and the commencement of cracking is considered in conjunction with the progress of martensite transformation. To conclude, there is a brief description of three thermal procedures which may be followed with a view to preventing cracks of this nature.—F.R.H.

A study of the soldering of tinplate. II. H. Morimoto and I. Tanaka (*Toyo Kohan*, 1956, **4**, Dec., 30–48) Surface factors influencing solderability are examined in detail.

Furnace brazing with nickel alloys at Fabriform Plant (*Ind. Heat.*, 1959, **26**, Feb., 417–418, 422) Batch furnaces and the practice for the brazing of heat-resistant steels with Ni–Cr or Ni–Mn alloys in purified H_2 atmospheres is described.—A.D.H.

Simple spray-brazing process makes tough jobs easy H. E. Miller (*Iron Age*, 1959, **183**, Jan. 29, 85–87) In the spray brazing process described a powdered Ni–Si–B alloy is applied to the joint through an oxy-acetylene flame. Advantages are the possibility of joining thin sections in hard-to-reach places. In the example given heat exchangers a remade with thin metal, and close-spaced tubes.—D.L.C.P.

Sterling-plus-lithium alloy selected for brazing B-58 stainless-steel sandwich panels A. A. Lanzara and A. M. Setapen (*Weld. J.*, 1959, **38**, Feb., 118–124) Compared with Ag–Mn alloy, sterling silver with lithium does not require a wetting agent, can be brazed at lower temperatures and gives a 10% stronger joint.—A.G.

Inspection of brazed joints: A statistical evaluation of some nondestructive methods R. R. Ruppender and E. G. Bianco (*Weld. J.*, 1959, **38**, Feb., 90s–96s) Five methods for the nondestructive inspection of brazing joints have been compared on the basis of precision, accuracy, and limitations. Results are presented as three-dimensional graphs or response surfaces.—A.G.

Brazing by the diffusion-controlled formation of a liquid intermediate phase J. F. Lynch, L. Feinstein, and R. A. Huggins (*Weld. J.*, 1959, **38**, Feb., 85s–88s) A method is described for brazing at temperatures below the melting point of any of the component parts. A liquid intermediate phase is generated by diffusion during the brazing process.—A.G.

Brazed steel honeycomb structures for 800°F C. F. Burrows (*Mat. Design Eng.*, 1959, **49**, April, 110–112) Selection of materials for cores and faces and of brazing alloys is considered and the properties of the honeycomb structures are given. Resistance to oxidation, to compression, and to bending are mentioned and a stress corrosion test on 17–7PH–RH950 steel in the atmosphere for 23 months showed no failure.

Acetylene economy in steel cutting M. S. Kerner (*Svarochnoe Proizvodstvo*, 1959, **32**, (5), 32–34) A description is given of an electromagnetic and a mechanical valve for control of the flow of acetylene during mechanical and manual cutting.—M.T.

Nitrogen-arc cutting of stainless steels I. S. Shapiro (*Svarochnoe Proizvodstvo*, 1959, **32**, (5), 30–32) Such cutting with a concentrated arc discharge is efficient on thicknesses up to 50 mm. Industrial N_2 with $\leq1\%O_2$ may be used; on stainless steel > 25 mm thick H_2 may be added to the N_2 to increase the heating intensity.—M.T.

Experience in the introduction of powder cutting of stainless steels in shipbuilding B. I. Smirnov (*Svarochnoe Proizvodstvo*, 1959, **32**, (5), 27–30) Mechanized powder cutting produces high cleanliness of the cut and bevels, but edges should be finished with an emery wheel. The effect on the edges of stainless steel is negligible and the structure of the steel has a fused dendritic structure some tenths of a mm thick along the cut. The edges were not affected by intergranular corrosion, and mech. props. were equal to those prepared by mechanical planing.—M.T.

MACHINING AND MACHINABILITY

Folisain–Wycliffe re-house fettling and machine shops (*Found. Trade J.*, 1959, **106**, May 5, 269–271) Improvements recently carried out at this plant in the fettling and machine shop are described, and an account of the newly-installed dust-extraction and air-heating equipment is given.

New line speeds structurals (*Iron Age*, 1959, **183**, April 9, 98–99) A unit for the fabrication of structural steel is described, comprising a cold saw, vertical and horizontal drills, and a shot blaster. Items are linked by conveyors and transfer skids.—A.G.

Studies on the mechanism of metal cutting K. Nakayama (*Bull. Fac. Eng. Yokohama Nat. Univ.*, 1959, **8**, March, 1–26) [In English] The angle between the cutting force and the shear plane is a function of the work material and rake angle. Distributions of shear strain, shear strain rate, and flow stress in the shear zone and on the tool face were established. The mean shear strain rate in the shear zone is some ten times that on the tool face. Equations are established to deal with the tool-chip contact length, chip formation parameters, and the effects of cutting variables (22 refs).—K.E.J.

Contribution to the method for stabilizing the optimum conditions for turning with cutting tools reinforced with hard alloy cutting edges P. Dodoc (*Met. Constr. Masini*, 1959, **11**, (3), 199–206) A theoretical study for calculating the parameters such as the effective force at the main spindle, torsional movement, feed pressure, etc. and the respective nomograms.

Chip formation in metal cutting: a hydrodynamic theory M. M. Lamm (*Engineering*, 1959, **187**, April 3, 444–446) A process in which the metal is regarded as squeezed plastically between the tool face and the body of the workpiece is formulated, Diagrams and micrographs of structures are shown, and various anomalies in other theories of chip formation are said to be explained.

A study of the effect of tool flank wear on tool chip interface temperature D. R. Olberts (*Trans. ASME: J. Eng. Ind.*, 1959, **81**, May, 152–157) The author has determined experimentally the effect on tool–chip interface temperature of wear lands, ground on the tools in order to provide uniform and accurate wear

measurement. The experimental variables were land wear, cutting speed, and cutting feed, and the tool-work thermocouple technique was used to determine interface temperature.—G. F.

Self-excited vibrations in metal cutting N. H. Cook (*Trans. ASME: J. Eng. Ind.*, 1959, **81,** May, 183–186) The author discusses qualitatively the basic mechanisms which cause self-excited vibrations of a cutting tool relative to the work, and also considers mechanisms inherent in the cutting process which can damp or limit vibrations. Experiments which are in agreement with the theory are presented.

Calculation of the parameters of the forces in the turning of Rumanian steels Gh. Casler, C. Buda, V. Bausic, A. Raileanu, G. Borzas, A. Rener, and D. Nicolescu (*Bul. Inst. Polytech. Jasi*, 1958, **4,** (1–2), 377–378, Group OL STAS 500–49; 379–380, Group OLC STAS 880–49) Nomograms are given for the various steels.

Calculation of the parameters for tangential machining D. Zoltan (*Met. Constr. Masini*, 1959, **11,** (1), 36–44) Relations are deduced for calculating the width, thickness of the chip, and the cutting force as a function of the geometry of the workpiece, the cutting tool with tangential advance and the instantaneous position of the tool during the advancing movement.

Controlled contact cutting tools B. T. Chao and K. J. Trigger (*Trans. ASME: J. Eng. Ind.*, 1959, **81,** May, 139–147) By suitably controlling the length of the tool-chip contact, a substantial reduction in power consumption has been achieved together with increased tool life, more effective utilization of cutting fluids, and improved surface finish on the workpiece. The reasons for these findings are discussed in terms of basic variables in chip formation mechanics.—G. F.

Mechanical finishing using flowing abrasive media C. H. Castle (*Plating*, 1959, **46,** Jan., 31–33) Parts are mounted on a spindle and immersed in a rotating mass of abrasive slurry. The method described is claimed to be faster than orthodox barrelling methods.—A. D. H.

The wear of abrasives in grinding G. J. Goepfert and J. L. Williams (*Mech. Eng.*, 1959, **81,** April ,59–73) A study of bonded abrasives, their reactions with the workpiece, their effect on abrasive wear and their modification by grinding fluids.

The influence of grinding on the distortion of the crystal structure of metals Yu. S. Terminasov and A. G. Yakhontov (*Metallov. Obra. Met.*, 1959, (5), 19–23) Grinding depths of 4, 10, 25, 37·7, 50, and 75 μ on U.8 steel and commercial irons with feed rates of 2·1, 3·9, 7·8, 13, 24, and 49 mm/rev. were used and machining speeds of 30 and 50 m/sec. X-ray diffraction and microhardness measurements were made. The decrease of distortion in the surface layer with rapid grinding is attributed to decrease in forces and not to heat generation.

Metallurgy in flat polishing A. Zimmerman (*Plating*, 1959, **46,** Jan., 34–35) The prevention and removal of stretcher strains by belt grinding are discussed.—A. D. H.

The effect of a lead additive on the machinability of alloy steels N. Zlatin and J. V. Gould (*Trans. ASME: J. Eng. Ind.*, 1959, **81,** May, 131–135) The authors present the results of turning tests, using carbide tools, on two medium-C steels with and without Pb addition and at several different hardness levels. The data show at what hardness levels the Pb additions are most effective.—G. F.

Grey cast iron machinability W. W. Moore and J. O. Lord (*Mod. Castings*, 1959, **35,** April, 55–60) A study has been made of common unalloyed cupola-melted grey cast irons to determine the relationship between microstructure and machinability.—A. G.

Present knowledge in machinability (Review of the literature published since 1956 (F. Rapatz and F. Motalik (*Stahl Eisen*, 1959, **79,** Sept. 3, 1285–1292) The review covers the following aspects: chip formation and tool wear; milling and grinding; machining of ultra-hard metals, and tool materials (59 refs).—T. G.

AISI 4340 low-alloy steel P. R. Arzt, J. V. Gould, and J. Maranchik jun. (*SAEJ*, 1959, **67,** May, 37–45) An investigation of the machining properties is reported. Turning, slotting, drilling, and tapping and a variety of milling tests were used.

CLEANING AND PICKLING

Improved ultrasonic cleaning J. Grindrod (*Prod. Fin.*, 1959, **12,** April, 82–83) A new magnetostrictive transducer developed by the Westinghouse Co. is described.

Acetylenic alcohol-inhibited pickling bath as a pretreatment prior to lining steel pipe K. N. Edwards, L. J. Nowacki, and E. R. Mueller (*Corrosion*, 1959, **15,** May, 275t–278t) Not only are propargyl alcohol and butynediol effective inhibitors in sulphuric acid pickling baths but they also reduce hydrogen embrittlement due to the acid. Steel pickled with either inhibitor present formed a better basis for epoxy-phenolic pipe linings than did a lightweight zinc phosphate coating. Lead ions in the pickle bath resulted in reduced coating life from baths without inhibitor or inhibited with propargyl alcohol. The possible mechanisms by which the alcohols improve coating performance are fully discussed. It is postulated that they polymerize into ring structures on the freshly cleaned steel and chelate the iron into the ring, so improving adhesion.—J. F. S.

Degreasing and pickling (*Corros. Prev.*, 1959, **6,** April, 52–56) A review of solvent and emulsion degreasing plant and of alkaline agents and proprietary preparations with a short section on additives for acid pickling solutions.

Experimental study on corrosion inhibitors used in pickling iron T. Bereczky and St. Kovacs (*Lucrari Stiintifice (Cluj)*, 1958, (1), 19–30) [In Rumanian] The experiments covered some of the undermentioned substances: (1) hydrophilic colloids, (2) active surface agents (*a*) sulphuric esters of the type R–OSO_3H where R is a radical with 16–20 C atoms; (*b*) sulphonated oils; (*c*) aromatic derivatives such as benzenesulphonic acid and other aryl derivatives, (3) various sulphur-organic combinations, (4) alcohols, aldehydes, ketones, (5) polycondensation products. Diagrams were constructed from measurements of the iron potential in acid solution in the presence of inhibitors. From these it may be seen that the potential of the electrode is displaced towards positive values. By potential measurements it was established that the above inhibitors have different effects, these are at present being studied. This method may be improved by electronic devices.

Surface treatment and material behaviour H. Wiegand (*Metalloberfläche*, 1959, **13,** Aug., 225–228) The interactions between surface layers and the base metal are discussed in general terms.

Pretreatment of cast-iron bushings for bearings before lining with antifriction metal R. Kuhn (*Stahl Eisen*, 1959, **79,** Sept. 17, 1356–1359) Anodic as well as cathodic processes are used in the pretreatment of cast-iron bushings. The electrolytic salt-bath treatment during the anodic treatment removes the graphite from the surface layer and, during the cathodic part of the treatment, the cast skin and residual moulding sand.—T. G.

Barrel finishing for plating M. M. Maynes (*Plating*, 1959, **46,** Jan., 36–40) A detailed description of barreling practice is given.

Electropolishing of high carbon steels S. Acimovic (*Werkstoffe Korros.*, 1959, **10,** June, 373–375) Following unsatisfactory results using standard H_2SO_4–H_3PO_4 electrolytes, with and without dextrine additions, a modified electrolyte was used with good results H_2SO_4 – H_3PO_4 – Cr_2O_3 – CrO_3 – $FeSO_4$ – CH_3COOH).

The mechanism of electropolishing K. F. Lorking (*J. Australian Inst. Met.*, 1959, **4,** May, 22–26) Theories are proposed to explain the mechanism of the macro- and micro-polishing processes by anodic dissolution. Discussion is restricted mainly to the behaviour of copper in H_3PO_4 solutions.—G. F.

The preparation of metals for electroplating J. J. Dale and I. J. Howell (*J. Australian Inst. Met.*, 1959, **4,** May, 27–34) The authors discuss the main stages in the preparation of metals for electroplating, outlining their functions and side effects. The types of difficulty which may arise are considered, and examples of methods of overcoming them are given.—G. F.

Shot-blasting installation for steel sheet and plate H. Chase (*Machinery*, 1959, **94,** May 20, 1150–1152) General Motors Corp. Oldsmobile division have installed plant for blasting 0·075 to $\frac{1}{8}$ in. hot-rolled steel sheet, which is described.

Brushes for surface finishing: 3 – Corrosion prevention and degreasing S. Wright (*Ind. Fin.*, 1959, **11,** April, 44–46) The author stresses the important role which brushes play in solving the problems associated with corrosion. Some of the different types which can be used for cleaning and degreasing for corrosion-prevention are described.—G. F.

Decementing solutions Grant & West Ltd (*Engineering*, 1959, **187,** April 10, 477) A note on a solution for the removal of cement and solidified aggregate from iron and steel.

A toxicity index for industrial wastes E. R. Hermann (*Ind. Eng. Chem.*, 1959, **51,** April, 84A–87A) Effects on the standard BOD test with $HgCl_2$ as comparison substance are measured.

Methods and chemicals commonly employed for the preparation of steel surfaces prior to painting J. H. Dudek (*IAAEJ*, 1959, **19,** March, 49–53) Solvent alkali, emulsion, and acid cleaning methods, pickling, and phosphating are reviewed.

Review of local authority bye-laws on finishing trade effluents in Monmouthshire Lord Meston (*Product Fin.*, 1959, **12,** May, 88–90) The new town of Cwmbran is included.

The treatment of waste pickling liquors and waste water from the ironworking industry by means of ion exchange membranes H. Quitmann (*Draht*, 1959, **10,** May, 225–229) Experiments are described leading to the small scale treatment and reclamation of H_2SO_4 pickling liquors by using chambers containing resin foil in various arrangements. Estimated costs of a full-scale plant, based on the laboratory trials are given, and assuming complete removal of H_2SO_4 and metal salts, with automatic operation.

PROTECTIVE COATINGS

An introduction to fundamental research on the mechanism of the electrodeposition of metals B. E. Conway and J. O'M Bockris (*Plating*, 1959, **46,** April, 371–383) An account for the practical plater of the kind of investigation undertaken and the sort of topic on which information is sought in research projects. Examples are given with results and a glossary is added.

Plating – yesterday, today and tomorrow A. K. Graham (*Plating*, 1959, **46,** Feb., 150–153; discussion 153) Suggestions are made for the improvement of quality of nickel plating. —A. D. H.

Trouble-shooting in the plating room W. Coulson (*Plating*, 1959, **46,** Jan., 45) A lecture The causes and elimination of plating defects are discussed.–A. D. H.

Abstract of papers presented at the All Union Scientific/Technical Conference on Corrosion and Protection of Metals, Moscow, USSR, May 19–24, 1958, Part I (*Plating*, 1959, **46,** Feb., 154–158) Detailed abstracts of seventeen papers dealing with cleaning, phosphating, improvements in plating processes, chromium plating, and chemical nickel plating are presented.

Rectifiers in the electroplating industry G. Schore (*Met. Fin.*, 1959, **57,** May, 55–58) A review of current rectifiers and their use for the deposition of Zn, Cd, Ni, Cu, Sn, Ag, Au, Cr, and various alloys as well as for cleaning and pickling. **II. Still tank plating** (June, 82–86) Ni, Cu, Zn, Cd, brass, and bronze, Ag, Au, Sn, and Cr plating and anodizing and electropolishing are briefly considered.

Specifications for protective plating: 1 E. A. Ollard (*Corros. Prev.*, 1959, **6,** March, 36–39) Specifications for the plating of various articles are suggested and discussed, reference being made in most cases to an appropriate British Standard specification.

Works studies and returns from operations in electrolytic surface treatment operations H. Maul (*Metalloberfläche*, 1959, **13,** June, 177–

180) The results of works studies carried out during a long period are analysed, with the aim of obtaining the best use of material and time in electroplating operations. It is shown in the departments investigated that more than 30% of the manpower can be freed for other departments, the profit from the works being increased at the same time.

Plating tests for solution control J. B. Mohler (*Met. Fin.*, 1959, **57,** April, 55–61) An account of a simple plating box and methods of using it for plating studies. The Hull cell, slot cell, bent cathode, flaring cell, and other devices, and covering power and plating range tests are described in general terms.

The chemical control of plating electrolytes K. E. Langford (*Electropl. Met. Fin.*, 1959, **12,** May, 163–167) Sampling and analysis are briefly reviewed in general terms with an introduction on the value of such controls. Future developments and requirements are forecast.

Dialysis for solution treatment in the metal finishing industry R. Dvorin (*Met. Fin.*, 1959, **57,** April, 52–54, 62) The general principle of dialysis is outlined, and its uses in metal finishing are named, with an account of the apparatus used, mainly for plating bath regeneration.

Continuous X-ray measurement of plating thickness P. S. Goodwin and C. L. Winchester (*Plating*, 1959, **46,** Jan., 41–44) A recording X-ray fluorescence spectrometer for the continuous measurement of thickness of copper, brass, nickel, and zinc on steel is described. The method is at least as accurate as wet chemical methods.—A.D.H.

Electroplating of automobile components J. M. Butler (*J. Australian Inst. Met.*, 1959, **4,** May, 61–70) The author describes one type of automatic plating machine used for the production of Cu–Ni–Cr plated parts in large volume. The process sequence is listed and the make-up and control of the various solutions is considered.—G.F.

New £500,000 plating plant at General Motors-Holdens Ltd Woodville Plant (*Austral. Eng.*, 1958, **50,** Oct. 7, 56–59) Features of the new plant for Cu, Ni, and Cr plating are described and illustrated.

Thicker decorative chromium for better corrosion resistance E. J. Seyb and W. H. Rowan (*Plating*, 1959, **46,** Feb., 144–149) An improvement in corrosion resistance of Ni–Cr or Cu–Ni–Cr deposits on steel or zinc-base diecastings is obtained when the thickness of the Cr layer is increased to 0·00003 to 0·0001 in.

Deposition of new chromium-iron alloy plate of banded structure L. O. McGraw, J. A. Gurklis, C. L. Faust, and J. E. Bride (*J. Electrochem. Soc.*, 1959, **106,** April, 302–305) A bath composition is given and a mechanism of formation is proposed. Plating rate and current efficiency are greater than for the conventional acid bath, but the plate is practically identical in properties.

Stainless steel and other product finishing problems F. H. Slade (*Prod. Fin.*, 1959, **12,** April, 68–77) A comparison of chromium-plated mild steel with stainless and of the fields of applications where these are alternatives. Plating processes and the mechanism of corrosion of Cr–Ni plating are considered. Degreasing, barrel cleaning, and finishing processes and also plating pretreatment are reviewed.

Engineering uses of plated coatings L. F. Spencer (*Met. Fin.*, 1959, **57,** May, 48–54) A review of Ni and Ni–Cr plating, of bearing metal deposition and their uses. A special section is devoted to electroforming, the metals used, and the parts produced.

A radioisotopic study of leveling in bright nickel electroplating baths S. E. Beacom and B. J. Riley (*J. Electrochem. Soc.*, 1959, **106,** Soc., 1959, **106,** April, 309–314) A radioactive addition agent, sodium allylsulphonate, was prepared and used in a Ni bath. Autoradiography and counting methods shows the material to be deposited preferentially on the high points of an irregular surface. It was also used in a study of lamination formation.

Evaluating the economy of reconditioning and coating underground steel pipe G. M. Pemberton (*Corrosion*, 1959, **15,** May, 279t–281t) A method of comparing the costs of replacing with new pipe and of reconditioning old pipe is illustrated by reference to an actual example of a 30-year-old 16-in. diameter, $\frac{1}{4}$ in. wall thickness buried bare steel gas main. This was reconditioned over approximately a half-mile length more cheaply than replacement would have cost. The spot welding and the wax coating and wrapping techniques used are described.—J.F.S.

Recent developments in enamels and enamelling J. Semple (*Inst. Vit. Enamel. Bull.*, 1959, **9,** April, 103–109) A review of work on enamel thickness, thermal expansion, fusing temperature, metal preparation, and enamel application.

An old answer to new chemical corrosion problems [Porcelain enamel] (*Ind. Eng. Chem.*, 1959, **51,** April, 77A–78A) Properties are noted and uses are listed.

240 vs 480 volt power for enamelling furnaces A. W. Levie and H. N. Hickok (*Ind. Heat.*, 1959, **26,** April, 714–726) Comparison of newly designed 480 v. enamelling furnaces with conventional 240 v. installations show that the higher voltage furnaces have lower initial and running costs, with no increased maintenance, shorter life, or less desirable operating control. Details of design of the two types are given.

Heat transfer through glassed steel E. J. Ackley (*Chem. Eng.*, 1959, **66,** April, 20 181–182) Cases in which anticorrosive efficiency outweighs thermal conductivity considerations are indicated.

Gasketing glassed steel equipment B. G. Staples (*Corr. Tech.*, 1959, **6,** May, 151–152) The use of polytetrafluorethylene-shielded gaskets and their installation has been examined.

Wear and tear of enamelled surfaces J. W. G. Pedder (*Inst. Vit. Enamel. Bull.*, 1959, **9,** May, 111–123) Scratch tests and abrasion studies on a wide range of enamel coatings are reported.

Determination of the porosity of enamels V. Halen (*Ceramics*, 1959, **10,** April, 17–18, 30; from *Silikattechnik*, 1956, (7), 150) A modified spark test in which the sparks are used to perforate paper is described.

Porcelain enamel defects; literature review and definitions C. E. Collum, G. Steiner, and T. A. Wastler (*PB* 151053, 1955, Sept., pp 121).

Priming of steel J. R. Rischbieth (*J. Australian Inst. Met.*, 1959, **4,** May, 35–48) The author deals with the priming of structural steel members, discussing the importance of good design, the effects of surface preparation and pre-treatment, corrosion protection by means of paint, and the selection of priming paints.—G.F.

CLAD SHEET AND HARD FACING

Hard facing in practice C. V. Whitehouse (*Austral. Eng.*, 1958, **50,** April 7, 66–83) The author deals practically with a series of hard facing applications, covering actual methods employed and embracing a wide range of industry from heavy earth-moving equipment to intricate tool and die work. Typical examples are described.—G.F.

Hardfacing with cobalt-base alloys G. Grainger (*Cobalt*, 1959, June, 3–15) Composition and properties, methods of deposition and uses are reviewed.

Stainless steel roll cladding (*Corros. Prev.*, 1959, **6,** April, 60) A brief note on the process as carried out at Hull.

Arc surfacing of components subject to abrasion with hard alloys M. A. Tylkin (**Svarachnoe Proizv.*, 1959, (5), 35–36) Stalinite (1·0%C, 9·5%Cr, 11·5%Mn) and Sormite (3·2%C, 30%Cr, 5·3%Ni, 1·1%Mn, 4·5%Si) ferrous alloys are described and their use in manual arc hard-facing is noted. The hardening of mill and crusher parts is outlined. The use of a B-containing alloy is also mentioned with examples.

Nickel-clad steel and Monel-clad steel (*Wiggin Nickel Alloys*, 1959, (51), 3–9) Make-up, tensile properties, heat conductivity, welding, and fabrication and bend-test values are given.

Development of titanium-clad steel using a vacuum-brazing process D. Canonico and H. Schwartzbart (*Weld. J.*, 1959, **38,** Feb., 71s–77s) A method is described for producing Ti-clad steel by a patented sandwich vacuum-brazing procedure. The procedures and joint designs necessary for making sound welds are described.—A.G.

Use of the plasma arc torch for applying refractory materials (*Machinery*, 1959, **94,** April 29, 963–964) A torch capable of depositing W, Mo, Zr, and Ta, carbides etc. is shown and the principle of its working outlined.

Hardfacing fusion, photo-cell controlled Deloro Stellite Ltd (*Metal. Prod.*, 1959, **103,** May 8, 819–820) A device using a photocell to control the movement of the oxy-acetylene torch on the Spray-Fuse unit giving smooth deposits on cylindrical components is described.

Carbide deposition (*Iron Steel*, 1959, **32,** April, 148) Equipment developed by Wickman Ltd, is described, which is named an 'Impregnator' and by means of which a layer of sintered carbide is applied to working surfaces such as tools and dies. The layer is deposited by a local sparking action, and is a building-up process rather than an impregnation.

New ceramic coatings give 3000 F protection A. V. Levy (*SAEJ*, 1959, **67,** April, 84–87) Flame-sprayed refractory coatings are reviewed and their properties and insulating effects are given. Reinforced ceramic coatings, at present experimental, are also surveyed.

POWDER METALLURGY

Powder metallurgy can compete with stamping J. Haller (*Prod. Eng.*, 1959, **30,** May 11, 82–83) Conditions under which thin metal parts can advantageously be made from metal powders are noted and examples are given.

Concerning the production of metallic powders A. Domsa, G. Muller, H. Colan, V. Nicolae, and V. Moldovan (*Lucrari Stiintifice (Cluj)*, 1958, (1), 91–97) [In Rumanian] Crushing by rotary blades, pulverization by a strong blast of inert gas at 3 atm pressure through a molten metal jet, and the electrolytic method are compared from the point of view of the energy required, and of the suitability of the finished product. The crushing with rotary blades is found to possess appreciable advantages.

Ferrous and non-ferrous powdered metal densities H. O. Schreiber (*Prec. Met. Mold.*, 1959, **17,** April, 48) A table for the computation of weight per 1000 pieces from volume in in^3.

Prototypes for iron powder parts (*Metal. Prod.*, 1959, **103,** April 10, 632) The machining of prototype parts for testing out of sintered blanks is briefly described.

Designing for metal powder structural parts J. L. Everhart (*Mat. Design. Eng.*, 1959, **49,** April, 113–124, Manual No.158) Properties, design, tolerances, finishing, economics, and uses are surveyed with diagrams and illustrations and tables of data.

How to do more with prealloyed powders W. L. Batten (*Met. Prog.*, 1959, **75,** April, 105–112) Examples of parts made from prealloyed steel powder are given, and it is pointed out that a variety of stainless steel and special powders are useful for corrosion-resisting, high-temperature, and electrical applications.

Researches into the preparation of iron powders of FREM type A. Domsa and A. Palfalvi (*Lucrari Stiintifice (Cluj)*, 1959, 411–425) FREM is the trade term for iron powders reduced with methane. A full description is given of the preparation of the raw material, reduction, compacting, and sintering. The advantages claimed are the large availability of the methane gas, the fineness of the powders so obtained, the ease of preparing sintered steel components, and their very good physical and chemical properties.

More sinterings in '59 cars (*Prec. Met. Mold.*, 1959, **17,** April, 34–35, 106) A review with descriptions and illustrations of parts.

Extruding metal powders E. Gregory (*Met. Prog.*, 1959, **75,** April, 113–116, 150–152, 154, 156, 158) Powders can be extruded in long bars, with various sections, to give good high-temperature properties. An outline of the techniques used, still mainly experimental, is given.

Applications of the endothermic atmosphere generator to the sintering of powder metal parts

N. K. Koebel (*Ind. Heat.*, 1959, **26**, April, 692–702) The author discusses the principle of operation of the endothermic atmosphere generator, and describes its application to the sintering of powder metal parts.—G. F.

Effect of sintering temperature on properties of iron–nickel–aluminium powder alloys A. B. Al'tman (*Metallov. Obra. Met.*, 1958, (12), 17–20) Alnico magnet alloy formation was studied. Sintering is accelerated by heating above incipient fusion point but density is reduced and also magnetic saturation, though coercivity is not affected. Non-ferrous examples are also mentioned.

The effect of mode of stressing in fatigue testing B. Cina (*JISI*, 1960, **194**, March, 324–336) [This issue].

A comparison of the various processes used for the production of sintered steel parts of high density F. Eisenkolb (*Stahl Eisen*, 1959, **79**, Sept. 17, 1345–1352) The author reviews the various processes possible to produce high-density sintered steel parts and describes his own experiments using one compacting operation and one sintering operation only. Other processes involving sintering in the presence of a liquid phase and the various modifications and combinations possible are enumerated. In the discussion, more recent developments are mentioned and the effect of copper as liquid-phase binder on subsequent case-hardening difficulties is pointed out.—T. G.

Type and causes of volume changes during the sintering of powder compacts of iron–copper-graphite mixture G. Bockstiegel (*Stahl Eisen*, 1959, **79**, Aug. 20, 1187–1201) Compacts of Fe–Cu powder undergo swelling and shrinkage during sintering. The reasons for these phenomena were studied and are explained. It was also attempted to express the volume changes mathematically. It is suggested that grain size of the Cu powder and the degree of perfection of mixing affect the volume changes. The addition of graphite is beneficial with respect to volume changes (swelling), this is attributed to the formation of an iron-rich ternary melt.—T. G.

Dilatometric, microscopical and X-ray studies of the shrinkage process occurring during the sintering of carbonyl iron powder compacts in the alpha- and gamma-phase G. Cizeron and P. Lacombe (*Stahl Eisen*, 1959, **79**, Sept. 17, 1366–1370) The authors report on studies of the sintering process that have been carried out by the Centre de Recherches Metallurgiques de l'Ecole de Mines de Paris, because of the increasing importance of powder metallurgy. The various subjects investigated are summarized, but the interpretation of the shrinkage of pores in the upper α-field is presented in some detail (22 refs).—T. G.

Researches into the characteristics of ball bearing steel powders and the conditions of their use A. Domsa, A. Palfalvi, and L. Botha (*Lucrari Stiintifice (Cluj)*, 1959, 387–396) [In Rumanian] On the strength of numerous experiments it was found that steel powder from ball bearings constitutes a cheap material of excellent quality for the manufacture of certain machine components with well-defined physical and mechanical properties. For example, piston rings made from these powders possess much better properties than those of machined components and are furthermore of uniform composition ensuring a most reliable product at a much reduced cost.

PROPERTIES AND TESTS

The significance of material specifications J. S. Anderson (*Austral. Eng.*, 1958, **50**, April 7, 55–59) In order to promote a better understanding of the principles involved, the author discusses the advantages and limitations of material specifications. The origin, objects, and uses of these specifications are described, and typical examples are given. Process specifications are also briefly considered.—G. F.

Material testing and correlation theory. I. Deductive treatment of the simple linear correlation H. Strauch (*Materialprüfung, Materials Testing, Matériaux Essais et Recherches*, 1959, **1**, May 20, 157–170) The author discusses the application of statistical analysis to testing methods, assessment of material quality and other cases, and points out the inadequacy of the inductive method of correlation to solve some complicated problems. He then develops a theory of correlation using deductive methods, and applicable to problems of simple linear correlation.

Complete investigation of the properties of cast irons V. P. Ciornobrovkin (*Studii Cercetari Metalurgie*, 1959, (1), 7–19) A method for full analysis of the properties of metals is proposed based on three kinetic curves: of cooling, contraction, and electrical resistance, obtained by means of a special apparatus. A relation has been established between the rate of cooling, the linear changes and the electrical resistance which is conditioned by the phase transformation during the cooling of the cast iron.

The influence of some metallurgical factors on the results of elasticity tests Y. Morillon, D. Lajeunesse, J. Plateau, and R. Boriono (*Journées d'Automne de la Soc. Française de Métallurgie*, 1958, Oct., 20–25, preprint, 23) Steels with various contents of pearlite were tested. Effects of P and N on transition temp. are assessed and the index $I = P + 5N$ is found to apply to tensile strength rather than to elasticity. Rolling temperature is also related to Mn content.

Development of the structure of steel under the influence of hot plastic deformation C. Rossard and P. Blain (*Journées d'Automne de la Société Française de Métallurgie*, 1958, Oct., 20–25, preprint, 14) Various transitory phenomena observed during torsion and tensile tests are described and discussed. The changes in structure are followed and note of deformation and other factors are taken into account.

Accuracy of the Erichsen cupping test V. Kokkonen and G. Nygren (*Jernkonts. Ann.*, 1958, **142**, (10), 638–660) The results of cupping tests in various laboratories (*a*) using their current practice, (*b*) after checking the machines and ensuring that specification DIN 50101 was adhered to. Influence of surface roughness and punch radius on cup depth was examined. Significant differences were found between results from different machines in both sets of tests, only partly attributable to differences in surface roughness and punch radii.

Commission on metallurgical tests (*Centre Doc. Sidér. Circ.*, 1958, (5), 1079–1084) A discussion on the Jominy test with special reference to scatter of results and limitations.—R. P.

Relaxation stability of high chromium steel Z. N. Petropavlovskaya, A. M. Borzduka, and A. V. Merlina (*Metallov. Obra. Met.*, 1959, (5), 45–50) Semi-ferritic steels with 0·1–0·15%C, 10–12%Cr, and 0·3–0·6%Mo were examined with reference to degree of alloying and phase state. Work-hardening was affected by alloying with V, W, Mo, Nb, and Ni. The tests lasted 1500–4000 h at 550–565°C with an internal specific load of 25–30 kg/mm². Additional alloying increased relaxation stability and simultaneous addition of all three elements is recommended. Sorbite to ferrite ratio, degree of hardening, and ferrite stability are important.

Using reflected light to detect and photograph defects on polished surfaces (*Machine Shop Mag.*, 1959, **20**, May, 263–267) The technique is described and examples are illustrated.

Cast surfaces evaluation for roughness standards E. Swing (*Mod. Castings*, 1959, **35**, May, 98–102) A method of evaluating visual comparator gauges for cast surfaces in accordance with standard specification MIL–STD–10A is described and discussed.

The nature of mechanically polished metal surfaces L. E. Samuels (*Electropl. Met. Fin.*, 1959, **12**, April, 130–133; May, 169–174, 178) Evidence is produced that polishing occurs by cutting and not by flow and that the Beilby layer does not exist. It is shown that the 'scratches' reappearing on etching after polishing are not grooves but slip line indications. The evidence for the covering of marks and pits by surface flow is also shown to be misinterpreted. Epitaxy methods and electron diffraction studies of surfaces are reported (74 refs).

Stress anisotropy in evaporated iron films J. D. Finegan and R. W. Hoffman (*J. Appl. Phys.*, 1959, **30**, April, 597–598) Stresses in films deposited at 22·5° to the normal 1000–3000 Å in thickness on microscope cover glasses 10^{-3} to $1{\cdot}5 \times 10^{-3}$ cm thick produced bending in the glass substrates which could be measured by interference effects. The ratio of the stresses in directions at right angles was 0·823 and 0·836 in two samples. By another method the absolute stress was determined to be 10^{10} dynes/cm².

The activities of iron and nickel in liquid Fe–Ni alloys G. R. Zellars, S. L. Payne, J. P. Morris, and R. L. Kipp (*Trans. Met. Soc. AIME*, 1959, **215**, April, 181–185) Vapour pressure measurements were made. Ni deviated negatively from Raoult's law over the whole range of composition, Fe behaves ideally down to 0·7 molar fraction. At 1600°C the activity coefficients at infinite dilution are 0·4 for Fe and 0·66 for Ni.

The solubility of carbon in molten iron–nickel alloys R. G. Ward and J. A. Wright (*JISI*, 1960, **194**, March, 304–306) [This issue].

Activities of iron and nickel in liquid iron–nickel solutions R. Speiser, A. J. Jacobs, and J. W. Spretnak (*Trans. Met. Soc. AIME*, 1959, **215**, April, 185–192) Solutions with 10–90 atomic %Ni were investigated between 1510° and 1600°C and a function is derived for graphical computation of activity from vapour phase composition. Negative deviations from Raoult's law were shown but ideality was approached as the temp. rose to 1600°C. Maximum heat of solution < -8 cal/mole and entropy $< -2{\cdot}5$ cal/mole/degree at 1510° changing negligibly with rise of temp.

Tensile testing machine for microscopic specimens D. M. Marsh (*J. Sci. Inst.*, 1959, **36**, April, 165–169) A device for testing whiskers or thin films attached to a projection microscope is described.

Non-destructive flaw and corrosion tester (*Process Control Autom.*, 1959, **6**, May, 213–215) The Introview eddy-current tester is described.

Diffusion and solubility of sulphur in iron and silicon iron alloys N. G. Ainslie and A. U. Seybolt (*JISI*, 1960, **194**, March, 341–350) [This issue].

The rectangular hysteresis loop of grain-oriented nickel iron alloy Tai Li-Chi, Liu Ren-pao, and Wang Li-ko (*Acta Met. Sin.*, 1959, **4**, March, 60–68) [In Chinese] The magnetic properties of 50%Fe–Ni alloy after various degrees of reduction and annealing treatments are reported. The development of a material for magnetic amplifiers is discussed (17 refs).

Magnetic properties of semiconductors: the Hall effect and magneto-resistance Demontvignier (*Rev. Gén. Méc.*, 1959, **43**, May, 255–262) After a general outline of the properties of semi-conductors, the author discusses the above characteristics, and considers briefly their possible industrial applications, with particular reference to Ge, Sb, and In.

The influence of the manufacturing process parameters on the properties of cold rolled transformer steel L. P. Ershova, M. I. Kolov, M. F. Kocher, L. V. Mironov, and F. N. Khisamov (*Stal'*, 1959, (8), 734–739) Extensive trials of methods of production and treatment are reported. The magnetic properties are shown to depend on degree of decarburization in black annealing and C should be reduced below 0·012%. Increased Si binders, C removal and increase of Mn from 0·10–0·16% increases specific losses and reduces magnetic induction.

Stress effect on the permeability of silicon steels A. Smolinski and Z. Kaczkowski (*Archiwum Elektrotechn.*, 1959, **8**, (1), 211–214) Stresses from rolling and extension of specimens have various effects on magnetic permeability, which were traced.

Control of magnetic particle testing J. W. Schweikert (*Met. Prog.*, 1959, **75**, April, 84–87) In view of the standard practice calling for regular suspension checks, and the fact that the check normally takes 30–60 min, a new method of checking by the use of a centrifuge which takes only 2 min is recommended.

Ferromagnetic domain sizes in polycrystalline silicon iron D. Bloor and D. H. Martin (*Proc. Phys. Soc.*, 1959, **73**, April 1, 694–695) A letter.

Sound waves detect flaws in metal (*Eng. Found.*, 1959, **24**, May, 35–38) A report on

exhibits at the Engineering, Marine, Welding, and Nuclear Exhibition in London in April.

Probing for faults with ultrasonics (*Metalw. Prod.*, 1959, **103**, May 15, 864–866) Apparatus produced by Kelvin & Hughes (Industrial) Ltd, is described and illustrated.

A universal calibration block for ultrasonic testing (*Lastechniek*, 1959, **25**, July, 149–151) After a brief introduction regarding the use of a calibration block when conducting ultrasonic tests of materials, there is a description of a universal calibration block evolved from extensive investigations conducted in Holland and other countries. The purposes of the block's different characteristics are briefly explained and a detailed line drawing of it appears in the text. The block weighs 5 kg.—F.R.H.

Introduction to ultrasonic testing. VI (*SS News*, 1959, March, 14–18) The use of the wall thickness gauge, flaw locating rule, and interferometer are described.

Radiography with a large cobalt 60 source V. G. Behal (*Nondestr. Test.*, 1959, **17**, May–June, 172–176) Procedure at Dominion Foundries and Steel Ltd, Hamilton, Ontario is described. Maximum thickness of plate for 2% sensitivity is >12 in. Sections under 3 in. require fine-grain emulsions. A fast, coarse-grained film gives good results for 4–10 in. plates, optimum 5–6 in. Edge losses for sections above 6 in. are large and above 7 in. special methods are needed. Grooves are easier to detect than holes of the same depth.

X-ray structure investigation of the highly coercive alloy Fe–Ni–Al–Cu I. N. Barutkin and B. Ya. Pines (*Fiz. Met.*, 1959, **7**, (1), 57–63) Under thermal treatment the Fe–Ni–Al–Cu alloy (55·9%Fe; 25·0%Ni; 14·5%Al; 4·0%Cu) breaks up into two phases. The coercive force H_c, depending on the thermal treatment, is accompanied by a change in the 'form' of the diffraction lines corresponding to phases β and β_2. The reason for the high H_c values is the dispersivity of particles of the ferromagnetic β-phase anisotropic in form and impregnated with the weakly magnetic material of the β_2-phase giving rise to considerable microstresses.

The identification of metals by X-rays F. Lafay (*Rev. Gén. Méc.*, 1959, **43**, May, 245–249) An outline is given of the principal X-ray diffraction techniques.

Radiographic stress measurements from line broadening V. Wolfstieg (*Arch. Eisenh.*, 1959, **30**, July, 447–450).

A high-temperature X-ray camera Z. Jiskra and B. Fleischer (*Hutn. Listy*, 1959, **14**, (4), 280–287) [In Czech] The development and use of an X-ray camera suitable for application a temperatures up to 1400°C are described.

X-ray studies of the lattice of metals subject to static and dynamic loading at normal and low temperatures T. S. Terminasov (*Hutn. Listy*, 1959, **14**, (1), 43–46) [In Czech] Studies of intergranular fragmentation were made on metals, particularly duralumin, at ordinary and liquid N_2 temperatures. X-ray line broadening was measured as a function of the strain.—P.F.

X- and gamma-radiography. Personal safety A. Goëau (*Centre Doc. Sidér. Circ.*, 1958, **15**, (12), 2561–2566) The maximum permissible dose of radiation is related to the safe radiation from a γ-source with and without screening, and the precautions necessary when using γ- and X-ray sources are discussed.

Methods of gamma radiographic control at the Laboratoire Central de l'EDF and their future prospects Ruault (*Centre Doc. Sidér. Circ.*, 1958, **15**, (12), 2533–2560) The materials tested, methods of irradiation, equipment used and techniques employed at the Central Laboratories of Electricité de France are described and discussed.

Gamma radiography in shipyards J. Spiro (*Shipbuilder*, 1959, **66**, April, 196–198) An account of the apparatus used is given.

Experience gained in the non-destructive testing of steel parts using a 15-MeV Betatron H. Krächter (**Stahl Eisen*, 1959, **79**, April 2, 419–426) A 15-MeV betatron developed for therapeutic purposes was used for the radiography of heavy steel parts that were too thick for examination by 300-kV X-rays or ^{60}Co. The betatron and the peculiarities involved in its use for the radiography of heavy steel parts up to 400 mm thick as well as the resolution obtained are described and discussed.—T.G.

Some particulars of the radiation control equipment used in gamma radiography A. Kohn (*Centre Doc. Sidér. Circ.*, 1958, **15**, (12), 2567–2570) An outline is given of the ionizing effect of radiation, and of apparatus for measuring the gamma radiation dose.

The effects of neutron irradiation on the properties of irons and steels D. R. Harries (*JISI*, 1960, **194**, March, 289–304) [This issue].

Experiments with radio-isotopes in measuring plate thickness Z. Remport (*Koh. Lapok*, 1958, **13**, Dec., 559–564) The author describes Hungarian experiments on measuring the thickness of 8–30 mm steel plates by using γ-radiation of ^{137}Cs and Geiger-Müller counters.—P.K.

Some metallurgical applications of radioactive isotopes W. R. Ellis (*Austral. Eng.*, 1958, Dec. 8, 61–64) Several examples are given of the use of radioisotopes in gauging, gamma radiography, and radioactivation analysis. Several applications of the tracer principle are described.

The effect of deuteron bombardment on the electrical resistance of the self-ordering alloys Ni_3Fe; Fe_3Al and on the ageing alloy Fe–Ni–Ti M. A. Artsishevskii, S. S. Vasil'ev, G. V. Koshelyaev, and Ya. P. Selisskii (*Fiz. Met.*, 1959, **7**, (1), 53–56) The bombardment was carried out with a stream of deuterons from a cyclotron with an energy of 4 MeV. The thickness of the specimens was between 20 and 30 μ which allowed interaction between deuterons and the lattice atoms over the entire volume of the specimens. The electrical resistance was measured by potentiometer and results are tabulated for the various alloys.

An atomic scattering factor for iron A. J. Freeman and J. H. Wood (*Acta Cryst.*, 1959, **12**, April, 271–273).

The electronographic determination of the structure of iron carbide Fe_3C Z. G. Pinsker and S. V. Kaverin (**Kristallografiya*, 1956, **1**, (1), 66–72) A structure with C at the corner of a cube is arrived at.

Symposium on radiation effects on materials. III (*ASTM STP*, 1959, (233), Feb., pp. 164). **Dosimetry techniques for gamma and reactor radiation fields** P. Schall and J. F. Kircher (3–20) (60 refs). **Irradiation facilities in NRU** G. C. Laurence (21–31). **The engineering test reactor as an irradiation facility** R. L. Doan (34–41). **An integrated facility for study of effects of nuclear radiation on materials** J. L. Colp and A. W. Snyder (42–49). **An in-pile fatigue testing apparatus** E. E. Drucker (50–61). **Reactor pressure vessel design for nuclear applications** N. Balai, T. L. Kettles, and R. E. Bailey (63–83) Creep and other performance data for high strength bolts and effects of irradiation on tensile properties of steels are given. **Effects of irradiation on the type 347 stainless steel flow separator in the EBR-1 core** R. E. Bailey and M. A. Silliman (84–102). **Radiation damage effects on reactor control materials** W. E. Ray, W. K. Anderson, add D. N. Dunning (103–126) Dispersions of rare earths in stainless steel are included.

On the sensitivity of the thermo-emf of the 'natural thermocouple' to the structure changes in the high speed steels M. F. Semko and L. S. Palatnik (*Fiz. Met.*, 1959, **7**, (1), 48–52) A special apparatus was used to measure the thermo-emf by the 'natural thermocouple' composed of R18 steels after appropriate heat treatment with one of the three following metals: copper, pearlitic cast iron, or St 5 steel. Between 20° and 800°C the thermo-emf of the natural thermocouple changes continuously (without jumps) during the different methods of heat treatment of R18 steel. At ~550°C the curves of the thermo-emf of the natural thermocouples R18 steel–St 5 steel and R18 steel-cast iron show a considerable lag with temperature, and the curve of the thermocouple R18 steel-copper has a maximum between 500–550°C. Up to 500°C the thermo-emf of hardened steel is lower than in annealed condition.

Measurements of thermal properties I. B. Fieldhouse, J. C. Hedge, and J. I. Lang (*WADC Tech. Rep.*, 58–274; *ASTIA Documen* 206892; *PB* 151583, 1958, Nov., pp. 79) Stainless types 316 and 347 and non-ferrous and non-metallic materials were examined and conductivity, specific heat, and thermal expansion were measured from 100–3000°F or to the m.p.

Fusion curve of iron to 96000 atmospheres: temperature of the earth's core H. M. Strong (*Nature*, 1959, **183**, May 16, 1381–1382) Iron at this pressure melts at 1740±15°C. Extrapolation to $1{\cdot}4\times10^6$ atm. gave a m.p. of 2340 ±50°C.

Fluidity of molten iron E. R. Evans (*BCIRA Bull.*, 1959, **14**, May, 772–775) A review. Composition and pouring temp. are the important factors.

Researches of the Central Scientific and Technical Institute of Machine Design and Construction on the subject of the science of metals and the technology of heat-resisting alloys E. P. Unksov (*Hutnické Aktuality*, 1958, **16**, 7–25) [In Czech] An account is given of work carried out at the Institute in Moscow on the development, applications, testing, and other aspects of heat-resisting steels for steam and gas turbines.—P.F.

Apparatus for the measurement of specific heat of metals W. H. Martin (*J. Sci. Instr.*, 1959, **36**, April, 179–182) Measurements up to 500°C in a vacuum can be made to ±3% with the electrically heated apparatus with adiabatic screen on hollow cylinder specimens.

Thermal properties of certain metals. Part II. Iron, Beryllium, Iridium, Palladium, Platinum, and Tungsten T. C. Goodwin jun. and M. W. Ayton (*WADC-TR-56-423* (Part II); *AD-157169*, 1958, Jan. 7, 321; from *Nuclear Sci. Abstr.*, 1959, **13**, April 15, 616) Abstracts 1920–1957.

The properties of steel at elevated temperatures: A review of the literature published during 1957 A. Krisch (*Stahl Eisen*, 1959, **79**, Aug. 6, 1146–1151) This part deals with: effect of chemical composition and effect of structure, and mentions briefly grey cast iron, non-ferrous metals, and powder-metallurgical products. 114 cumulative references.—T.G.

Properties affecting suitability of 9 percent nickel steel for low-temperature service T. M. Armstrong, J. H. Gross, and R. E. Brien (*Weld. J.*, 1959, **38**, Feb., 57s–65s) The effect of some fabrication operations on the properties of a low-carbon 9% nickel steel is described. Tensile properties of the nickel steel plate and of the plate welded with Inconel-type wire have been investigated down to −320°F.

The low-temperature mechanical properties of some cast stainless steels G. Mayer and K. Balajiva (*Metallurgia*, 1959, **59**, May, 221–226) The mechanical properties of a number of cast austenitic stainless steels, stabilized, and unstabilized, between 100° and −196°C. Lower C contents gave improved impact properties at both low and high temperatures with the stabilized steels, and it was found that cast 18/8 steels with 0·1–0·14%C in the annealed condition gave a useful combination of tensile and impact properties for low-temperature application.

Introduction to the study of the phenomenon of diffusion in metals A. de Sy (*ATB Métallurgie*, 1956, **1**, (1), 16–22) The application of Fick's laws to approximate calculations in the case of dilute binary solutions is discussed; the limitations of these laws are reviewed. Examples of the application of Fick's laws to the diffusion of C in Fe are given (11 refs).

New determination of integranular diffusion constants for face-centred cubic iron C. Leymonie, Y. Adda, A. Kirianenko, and P. Lacombe (*Compt. Rend.*, 1959, **248**, March 9, 1512–1515) The sectioning method was used on polycrystalline cylinders of iron using radioactive tracers of ^{55}Fe and ^{59}Fe at 580–616°C.

Hydrogen in steel and its consequences P. Bastien (*ATB Métallurgie*, 1958, **1**, (5), 127–130) Topics discussed are the solubility of H_2 in Fe and its alloys, methods of determination of H_2 in steel; the mechanism of its entry into steel and its partial removal during manufacture, the effects on steel properties of its presence. Reference is made to the problems created by the presence of H_2S in the Lacq natural gas deposits.

Effects of hydrogen in wrought steel and in ferrous weld metal P. D. Blake and W. I.

Pumphrey (*Brit. Weld. J.*, 1959, **6**, May, 211–224) A review of recent work on the effects of H_2 in which it is shown that the effects on steel and weld metal are much the same allowing for differences in composition and microstructure. Impact values, tensile properties, fatigue, and cracking are considered (67 refs).

The effect of hydrogen on cold crack formation during the welding of medium-alloy steel E. A. Kozlov (*Svarochnoe Proizvodstvo*, 1959, **32**, (4), 17–22) A study was made to obtain a quantitative relationship between the H_2 content of the weld metal and cold crack formation in welded joints at various contents of alloying elements in the base metal. Cr–Ni–Mo steel was butt-welded and the content of free carbon in the deposited metal was determineel and the carbon equivalent of the base metal was calculated. The results show that embrittlement is due to a combination of too high carbon equivalent (>1%), an excessive cooling rate causing greater hardenability of the steel and slower H_2 diffusion, and H_2 content in excess of a critical level. Either of the two latter factors may cause momentary complete or partial loss of plastic properties, and couples with deformations and stresses set up during welding in excess of the creep limit, so that where the metal cannot be deformed by up to 0·5–1%, cold cracks occur. The solution is appropriate welding parameters, reduction of the carbon equivalent and a reduced H_2 content.—M.T.

Effect of hydrogen on the magnetic behaviour of iron and iron alloys F. Erdmann-Jesnitzer and I. Bohm (*Materialprüf.*, 1959, **1**, Feb. 20, 43–53) Three types of sheet all 1 mm thick were cathodically charged with H_2 after various degrees of working. In all cases a rise in coercive force was found during cathodic charging. Later and at the end of cathodic charging the coercive force decreased, but in no case reached the original level. One of the sheets contained Si 0·77%, this sheet showed a reduced uptake of H_2 as compared with the other sheets. The mechanism of H_2 evolution and its effect on magnetic properties, on substructures, dislocations, and other imperfections is briefly discussed.—T.G.

On the properties of pure iron cathodically charged with hydrogen in presence of sulphur, arsenic or antimony S. Besnard, C. Messager, and J. Talbot (*Compt. Rend.*, 1959, **248**, March 9, 1516–1519) Optical and electron-microscopy shows intergranular precipitation which embrittles the metal.

The effects on resistivity of proton-diffusion in steel after charging [with hydrogen] in an acid medium and after plastic deformation E. Herzog and M. Hugo (*Compt. Rend.*, 1959, **248**, Jan. 19, 408–410) Killed mild OH steel was used and corroded for various periods in solutions of H_2S. After straining, resistivity was measured and curves are shown.

Nitrogen in steels K. G. Speith and H. vom Ende (*J. Metals*, 1959, **11**, May, 333–338) An outline is given of the effects of N_2 in steel, and its removal in pneumatic and OH processes.

Nitrogen contents of steels manufactured in the electric furnace Colin (*Centre Doc. Sidér. Circ.*, 1958, **15**, (12), 2515–2523) The N_2 contents of various types of rimming and killed electric furnace steels are reported and tabulated.

The solubility of nitrogen in liquid iron–molybdenum, iron–nickel, and iron–vanadium alloys M. G. Frohberg and H. Graf (*Stahl Eisen*, 1959, **79**, April 2, 431–433) A review and summary of recent published work. The results are presented in diagrams.—T.G.

Solubility of oxygen in alpha-iron: a revision A. U. Seybolt (*Trans. Met. Soc. AIME*, 1959, **215**, April, 298–300) With a purer iron values at least an order of magnitude lower were obtained. It appears to be about 0·002%O or less.

Molybdenum and the thermal treatment of steel D. Iturrioz (*Met. Elect.*, 1956, **20**, Dec., 53–60) [In Spanish] In this, the first part of the article, the author discusses aspects of heart treatment such as mass effect and temper brittleness and refers to the beneficial effects of molybdenum. The advantages to be gained from adding Mo to steel are summarized.—P.S.

Effect of aluminium on the hot workability of low carbon steel T. Akutagawa, Y. Mishima, E. Asano, and A. Suseki (*Ann. Rep. Eng. Res. Inst. Univ. Tokyo*, 1959, March, 54–59) [In Japanese] Results from hot bending, hot torsion, and microstructure tests are given. Non-metallic inclusions containing Al obstruct deformation during hot rolling.—K.E.J.

Some problems of the addition of alloying elements to special high-alloy casting alloys Yu. A. Nekhendzi (*Prz. Odlew.*, 1959, **9**, (2), 33–40) In this article, translated from Russian, a report is given of research into the properties of heat-resisting iron- and nickel-base alloys. It was established that apart from the effect of the individual alloying elements on the properties of the alloys a decisive influence is exerted by the cooling rate, the time of solidification, and the degree of feeding of the castings. The maximum heat-resistance for a given matrix is obtained at that content of toughening and carbide-forming elements, which will still maintain equilibrium of the austenite without the formation of δ-ferrite, which in due course breaks down into the brittle σ-phase. This hypothesis was used to develop a series of heat-resisting Fe–Cr–Ni alloys with a relatively low Ni content (10–15% in place of 25–35%) and no Mo, but with the addition of N (0·01% of Cr content).—N.T.

The role of boron in cast austenitic alloys R. W. Kraft jun. and R. A. Flinn (*Trans. ASM.*, 1959, **52**, preprint 133, pp. 34) Changes of properties at high and ordinary temperatures produced by contents of up to 1·5%B are given. The effects of the precipitates formed are of wider application also. Above 0·3%B a brittle boride network results which greatly reduces elongation at ordinary temperature. Tensile properties at 1500°F increase with additions of B, the massive borides have little effect but a precipitate forms in the matrix areas which is of greater significance. Creep properties are improved by pretreatment at 2150°F which conditions the specimen for precipitation under stress, sepecially at sub-grain boundaries.

The influence of sulphur on the mechanical and refractory properties of cast pearlitic steel 15Kh1MiFB A. F. Silaev and E. F. Dubrovskaya (*Metallov. Obra. Met.*, 1959, (5), 40–44) The steel has 0·18%C, 0·3%Si, 0·61%Mn, 1·42%Cr, 1·2%Mo, 0·33%V, 0·51%Nb, 0·12%Ni, and 0·012%P. Sulphur levels of 0·01, 0·03, and 0·066% were examined. Creep properties were determined after two heat treatments. Plasticity and impact strength are reduced by S and embrittlement is accelerated. Sulphide inclusions were often foci of failure. A limit of 0·02–0·025%S is suggested.

Copper-bearing steels H. Bessart and J. Liegeios (*Rev. Soud.*, 1959, **15**, (1), 30–43) The mechanical properties, weldability, and resistance to corrosion of Cu-bearing steels are examined in detail, including behaviour at elevated and low temperatures (45 refs).

The influence of the rarer metals on the mechanical properties of iron–aluminium alloys E. M. Savitskii, V. F. Terekhova, and I. V. Burov (*Metallov. Obra. Met.*, 1959, (3), 38–43) Using high-purity Fe and Al, the effects of Zr, Ti, Ta, Nb, V, B, Mo, and Ce were observed. Hardness, strength, ductility, and inclusions were studied. Embrittlement is due to oxides, grain refining (with 15–16%Al) is produced by Ti; Ce+Zr or Ce+V. Hardness is increased by 0·05–0·2%B and V; strength by 0·05%B, 0·2%Ta, or 0·5%Zr, including impact strength. The metal can be rolled and the magnetic properties were determined; resistance to corrosion is high.

Engineering properties and applications of Ni-resist irons International Nickel Co. (*Pamphlet*, 5th edn., 1958, pp. 68) Mechanical properties, compositions, structures, resistance to wear and corrosion, electrical and magnetic properties, and a large illustrated section on uses are given with an extensive table of resistance to corroding agents.

Unalloyed tool steels (*Stahl Eisen-Werkstoffblatt*, 150–58, 1958, Sept., 3rd edn., pp. 8) The steels of this specification contain 0·06–1·4%C and may have <0·3%Si and <0·35%Mn. For special purposes slight deviations from these analyses are allowed. The chemical analysis of the various grades of these steels are listed and heat-treatment and hot-working data are presented in tables.—T.G.

French special steels in 1958 R. Morizot (*Mét. Constr. Méc.*, 1959, **91**, May, 361–362, 363) The Presidential Address given at the General Meeting of the Chambre Syndicale des Producteurs d'Aciers Fins et Spéciaux, dealing with the production figures of French special steels, with particular reference to the inauguration of the European Common Market.

Cold-working alloy steels *Stahl Eisen-Werkstoffblatt*, 200–58, 1958, Sept., 2nd edn., pp. 8) The steels of this specification are used for tools for forming and machining and comprise therefore a large variety; the use of each steel is indicated. Chemical analysis of the various grades, hardness in the various stages of heat treatment, and the temperature for hot-working and heat-treatment are presented in tables.—T.G.

Hot-working alloy steels (*Stahl Eisen-Werkstoffblatt*, 250–58, 1958, Sept., 2nd edn., pp. 8) The steels of this specification are defined and classified in four groups according to the main alloying elements and their application. Chemical analyses of the various grades, ultimate strength after heat-treatment, and temperature for hot-working and heat-treatment are presented in tables. The effect of tempering temperature on hardness is plotted for each steel.—T.G.

Cr–Mn–Ni–M Austenitic utility steels K. Hýbek, J. Sole, and M. Zezulova (*Hutn. Listy*, 1959, **14**, (4), 287–297) [In Czech] The development, testing, and use in production of several types of stainless steels in which Ni has been partly replaced by N are described. Of these one was found to be outstanding and was studied in detail. Production technology had to be modified from that recommended in the literature; the unmodified process yielded inferior steel.—P.F.

45 KhTs chromium zirconium steel G. L. Livshits and G. A. Torpanova (*Stal'*, 1959, (8), 742–744) Steel with 0·4–0·48%C, 0·5–0·8%Mn, 0·17–0·4%Si, not more than 0·035%S or P, 0·8–1·1%Cr, and 0·15–0·25%Zr was superior to 45 Kh steel for hardenability and fatigue strength. Its use for suspension spring arms and crankshafts proved advantageous. Properties after running 32 000 km are given.

High-speed steels (*Werkstoffblätter Verein Deutscher Eisenhüttenleute, Stahl-Eisen Werkstoffblatt* 320–59, 4th edn., April, 1959, pp. 6) This specification comprises tool steels used for machining at high speeds, the steels are melted in the electric furnace. Hot working and heat-treatment is dealt with in detail.—T.G.

AM-355 high-strength stainless G. N. Aggen (*Iron Age*, 1959, **183**, April 2, 74–77) The material has 15%Cr, 4%Ni, 3%Mo, 0·1%N, and <0·15%C. It can be treated to resemble an austenitic stainless or a hardenable stainless steel. Properties are given and machining and welding are considered.

Influence of alloying on hardening and softening of iron-base heat-resistant alloys D. F. Zhirnov (*Metallov. Obra. Met.*, 1959, (3), 17–19) C, V, Al, Mo, W, and Mb were studied as additives to 13%Cr–8%Ni–8%Mn alloy to an extent of ~3 at %. In the case of metallic additions C was kept below 0·07%. Specimens were annealed after 50% reduction and hardness was measured. V has little effect on softening and W retards it. The sharp fall in hardness occurs at recrystallization temp. and fine-grained structures appear in the deformed regions. Structures are shown and discussed and the effects of the alloying elements are indicated.

Four new stainless alloys N. S. Mott (*Iron Age*, 1959, **183**, April 16, 118–121) The development of a series of cast alloys combining strength and corrosion resistance is reported. The mechanical properties and corrosion rates of these Mo-containing 18/8 type alloys are listed.—A.G.

Corrosion resistant, ageing Armco steel–Armco 17-7 PH (*Draht*, 1959, **10**, May, 222–224) The composition, properties, and treatment are described of this steel, which contains 16–18%Cr, 6·5–7·75%Ni, 0·75–1·5%Al, and up to 1%Si.

Tool steels: with a directory of AISI types (*Iron Age*, 1959, **183**, April 30, 109–124) Sec-

tions on water-hardening steels and their treatment, shock-resisting grades for tooling, uses of cold work steels, hot work steels for tools and structures, high-speed tool steels for machining, and special purpose tool steels are followed by tables of brands with the name of the maker.

Can Fe–Cr–Al alloys ever replace stainless? P. M. Unterweiser (*Iron Age*, 1959, **183,** Feb. 5, 90–92) Renewed interest in Fe–Cr–Al alloys since vacuum melting became a practical process is explained. Two recent reports are reviewed. One class of these alloys is reported to have excellent resistance to the combustion products of residual fuel oils ('vanadium pentoxide attack'). Some promising mechanical properties are also quoted.—D.L.C.P.

Extensions to Swinden Laboratories: Pilot plant to aid steel research (*Iron Coal Trades Rev.*, 1959, **178,** April 3, 769–771).

United Steel's new pilot plant laboratory block (*Metallurgia*, 1959, **59,** May, 234–236) A description with photographs of the self-contained laboratory for pilot plant studies on fuel and furnace research at United Steel's Swinden laboratories at Rotherham.

The Commonwealth Steel Company Limited: New metallurgical and chemical laboratory (*Austral. Eng.*, 1958, **50,** April 7, 76–78) Details are given of the design and layout of the new metallurgical and chemical laboratory block at the Waratah works of this Company.

METALLOGRAPHY

Collective research in the fields of metallography and metallurgy A. Portevin (*ATB Métallurgie*, 1956, **1,** (1), 1–4) The author emphasizes the increasing need for collective research, from the points of view of actual research, dissemination of results, and science teaching; he outlines the collective research work being done in France and Belgium, and makes special reference to IRSID.

Determination of mechanical properties of steel by quantitative metallography N. N. Lyulicheva (*Fiz. Met.*, 1959, **7,** (2), 265–273) In the tempering range between 450–700°C there exists a relation between the quantitative measurements of structure characteristics and the strength characteristics of steel. An empirical formula is proposed for determining the yield point, which is valid both for carbon steels from 0·3 to 1·06% and for 45 G 2 and 60 S 2 alloy steels. A linear relation has been discovered between the uts and the inverse specific area of the ductile phase.

The electrolytic pretreatment of metals for metallographic investigations with a new type of instrument F. Rämmele (*Technik*, 1959, **14,** Jan, 46–50) A new instrument by Carl Zeiss is described, consisting of a combined optical microscope and electrolytic cell, by means of which a metal specimen can be observed continuously during electrolytic polishing and etching.

Microscopes: modern design of optical equipment (*Met. Treatment*, 1959, **26,** April, 155–158, 160) An illustrated review of recent designs.

Contribution to the study of errors occurring in quantitative microscopical analysis V. Hevia Rodriguez (*Inst. Nac. Carbon Bol. Inf.*, 1959, **8,** March–April, 73–80) A graphic statistical method of dealing with point-count microscopical analysis of coal constituents is presented.

Use of the electron microscope: Study of creep in a chromium–molybdenum steel K. F. Hale (*Met. Treatment*, 1959, **26,** April, 145–153, 160) Stressed and unstressed specimens were examined at 550–675°C for times up to 20000 h. The microstructures of the specimens were similar so long as the tertiary stage of creep was not reached. Stressed specimens showed similar structures, the creep test time ratio of 580° and 650°C specimens was ~10:1. At the beginning of creep a fine acicular precipitate appeared which was replaced by a coarser precipitate during secondary creep and during the third stage it spheroidizes and the separation between particles increases. In this steel changes in matrix composition have an effect on creep strength as well as changes in the precipitates.

Modifications in the preparation of carbon extraction replicas from austenitic steels I. Hrivňák (*Hutn. Listy*, 1959, **14,** (3), 211–214) [In Czech] A modified method of preparing extraction replicas from 18/8 and 16/13 type stainless steels utilizing shadowing of the negative side of the films with chromium is described.—P.F.

Carbon carrier foils and replicas in electron microscopy and diffractography M. Rozsival (*Hutn. Listy*, 1959, **14,** (4), 307–309) [In Czech] The preparation and use are described.—P.F.

The micrography of nitrided zones in the optical and electron microscope M. Koch (*Metalloberfläche*, 1959, **13,** Aug., 242–245) It is pointed out that the properties of nitrided layers depend to a great extent on the structure and composition of the base metal and the nitriding conditions. These factors are illustrated by several optical and electron micrographs.

Discussion on carbides in annealed and quenched high-speed steels (*JISI*, 1960, **194,** March, 364) [This issue].

Study on segregations of copper and tin in the case of a small ingot for special shaped steel T. Akutagawa, Y. Mishima, E. Asano, and A. Suseki (*Ann. Rep. Eng. Res. Inst. Univ. Tokyo*, 1959, March, 47–53) In small killed ingots of low-carbon steel, tin concentrates in segregation zones at the top and bottom of the ingot, but appears to have little influence on surface crazing during hot rolling.—K.E.J.

The influence of surface structure on current density and potential on electrodes H. Sundermann (*Arch. Eisenh.*, 1959, **30,** June, 371–380) An investigation is described on the influence of surface structure on current density and potential distribution on rough electrodes, and the significance of the results for the electrolytic isolation of structural constituents is discussed (20 refs).

Macrographic methods for detection of lead inclusions in steel A. Kohn (*Centre Doc. Sidér. Circ.*, 1958, (7), 1515–1518) Two methods are described, involving etching out the lead inclusions, from polished specimens, on to gelatinous paper soaked in NaOH or acetic acid and developing the image with Na_2S and H_2S respectively. Sharp images are obtained and the relative merits of these processes are compared. An electrolytic method giving rather inferior results is also mentioned.

On the role of the secondary recrystallization in texture formation in annealing cold-rolled transformer steel L. V. Mironov and G. N. Shubin (*Fiz. Met.*, 1959, **7,** (2), 312–313) It has been shown that when heating cold-rolled transformer steel above 900°C, secondary crystallization occurs which is considered as a particular case of grain growth. The most complete texture is obtained with an initial recrystallization temperature of 900–950°C. At this temperature the number of properly oriented grains ('growth centres') increases and they attain during holding at this temp. sizes up to a few hundredths mm^2 when between 90 and 95% of the texture is complete.

Grain in cast iron. A general study M. Ferry and J.-C. Margerie (*Fonderie*, 1957, July, 303–315) Extracted from a report presented by the Centre technique des Industries de la Fonderie at the Annual Congress at Atlantic City in May 1956. A general discussion is given on the effect of cooling conditions and composition on grain size.

Ordering and recrystallization of self-ordering Fe–Co alloys M. M. Borodkina, E. I. Detlaf, and Ya. P. Selisskii (*Fiz. Met.*, 1959, **7,** (2), 214–224) A connexion has been established between the temp. range of recovery and the composition of the Fe–Co alloys. The initial splitting of the Kα-doublet + line in the X-ray spectrum represents the first stage in the recovery and is observed at the lowest temperatures in the alloys Fe_3Co, FeCo, and $FeCo_3$ of stoichiometric composition. This is due to the fact that a number of self-ordering alloys have less strength after thermodynamical deformation. The recrystallization of self-ordering Fe–Co alloys begins at the transformation temperature. The highest initial temperature of recrystallization is that of an alloy with the stoichiometric composition FeCo.

Observations on the recrystallization of a silicon–iron crystal in a polygonized matrix Hsun Hu (*Trans. Met. Soc. AIME*, 1959, **215,** April, 320–326) Recrystallization was weak in the central portions of a 70%Si–Fe cold-rolled crystal, but in the edge regions, recrystallization was rapid. In the polygonized matrix a few recrystallization nuclei were present appearing as small grains. Recrystallization tendency appears to be related to severity of lattice bending rather to difference in orientation of deformation texture.

Influence of inoculants on the crystallization and sulphur distribution of cast austenitic steel N. S. Kreshchanovskii and I. E. Zabludovskii (*Metallov. Obra. Met.*, 1959, (3), 33–37) A tracer study was made of steel from an acid-lined electric furnace with 0·04%S (1 μ curie/kg). Effects of Zr, Ce, and Ca are noted.

On veining in ferrite F. Erdmann-Jesnitzer and A. Dieter (*Hutn. Listy*, 1959, **14,** (3), 201–206) [In Czech] Veining was studied by electron micrography and micro-hardness tests. The veins are removable by heat treatment. They do not consist of precipitates of carbides, but appear to be due to the diffusion of impurities to dislocations.—P.F.

The polygonisation and recrystallization behaviour of pure iron in respect of the production of single crystals A. Kochendorfer and H. Ewertz (*Arch. Eisenh.*, 1959, **30,** July, 441–445) Pure Fe, containing 0·022%Si and < 0·005% remaining impurities showed neither polygonization nor recrystallization in the initial structure with about 20 grains/mm obtained by a γ→α transformation, when annealed below 500°C with up to 30% strain. At temperatures above 800°C and with 15–20% strain, polygonization occurred with a coarsening of structure. Long crystals were obtained in the γ→α transformation in a furnace with a temperature gradiant, in specimens which were subsequently annealed in H above and below the A_3 point.

Crystallisation of the lamellar iron graphite eutectic in cast iron W. Patterson and D. Ammann (*Giesserei. Techn.-wiss. Beih.*, 1959, Jan., 1247–1275) The principles of nucleation and crystal growth are reviewed and applied to the lamellar Fe–C eutectic. It is maintained that the eutectic graphite in non-heat-treated iron is formed directly from the melt. It is estimated that the number of effective nuclei varies between 10^{-12} and 10^{-2}%. The nature of substances that can act as nuclei is discussed The effect of superheating on supercooling and microstructure was studied and the results reported (91 refs).—T.G.

Graphitisation in cast iron–carbon alloys A. Wittmoser (*Giesserei.*, 1959, **46,** April 9, 177–187) A general discussion of graphite formation in all groups of Fe–C materials is followed by detailed consideration of the mechanism of formation of the five main types of graphite-lamellar kish, lamellar eutectic, temper carbon, 'undercooled' lamellar graphite, and spheroidal graphite. Formation of graphite in solid systems is discussed, and the article concludes with an appendix dealing with the possibility of the formation of spheroidal graphite in the interior of blowholes (44 refs).

Contribution to the study of the kinetics of the graphitisation of the white cast iron M. Ferry (*Fonderie*, 1957, Oct., 445–457) In applying to industrial cast iron the work reported by Brown and Owen (*JISI*, 1954, Feb., 147–155) giving the law governing high-temperature graphitization of a synthetic Fe–C–Si alloy, the author finds that the following law is valid over a wide field for the case of cast irons without a preliminary heat treatment: $y/1-y=(t/k)^n$, where n has a mean value of 2·5. The results are discussed for irons with and without a preliminary heat treatment.

The effect of casting wall thickness on the quantity and size of temper carbon precipitates in blackheart malleable iron J. Raczka (*Prz. Odlew*, 1958, **8,** (10–11), 321–328). After a review of existing theories of graphite nucleation in such iron and the effects on this nucleation, of chemical analysis, gases, thermal stresses, etc. experiments are described to reveal the effect of casting wall thicknesses on the structure of tempered specimens (wall thickness 4–24 mm) in the raw state, after machining and after chemical treatment (10%

solution H_2SO_4 for up to 8 months), to reveal the size and number of graphite aggregates per unit area. In all instances these aggregates were found to be in direct relationship to the wall thickness of the specimens regardless of their state.—M. T.

Experimental studies on the formation of superlattice in FeCo alloy T. Yokoyama (*Bull. Fac. Eng. Yokohama Nat. Univ.*, 1959, **8**, March, 27–80) [In English] Results of tests on thermal, magnetic, electrical, and other properties are given. The formation and destruction of the superlattice are reversible. It is formed by cooling from high temp.; at 730°C ordering begins and a further critical temp. is 550°C when the degree of ordering increases markedly (39 refs).—E. E. J.

The formation of cubic texture in nickel–iron alloy L. C. Tai, S. Y. Chang, and R. P. Liu (*Acta Met. Sin.*, 1959, **4**, March, 52–59) [In Chinese] In 50%Ni–Fe, the cubic structure begins to form at 600°C. It was sharp and complete in a sample cold-reduced by 98·4% and annealed for 1 h at 1100°C. It is formed by rotation of ~(123) [$1\bar{2}1$] orientation about the 111] axes by 40° (11 refs).—E. E. J.

Effect of boron on the nature of carbide segregation in austenitic steels during tempering V. V. Levitin and V. I. Syreishchikova (*Fiz. Met.*, 1959, **7**, (2), 308–310) Boron slows down the separation of the excess phase from austenite of varying composition (carbon, alloy, and austenitic steels). The surface activity of boron manifests itself in alloys on a nickel base and in iron. The radius of the boron atom is smaller than the radii of the atoms in the above-mentioned solid solutions. This should result in a higher solubility of boron in the distorted boundary zones than in the body of the grain.

Various treatments of melt and S-curve in molybdenum and nickel cast iron T. Ototani, Y. Tokunaga, and N. Takahashi (*Imono*, 1959, **31**, Feb., 84–93) [In Japanese] The S-curve for 0·5%Mo, 1·4%Ni shows two major portions, corresponding with pearlite formation in the temp. range 720–520°C and bainite formation in the range 520–200°C. The influence of graphite in various forms on the transformations is discussed (13 refs).—E. E. J.

Influence of degree of stabilization on the precipitation processes of niobium-bearing austenitic chromium–nickel and chromium–nickel–molybdenum steels K. Bungardt, G. Lennartz, and K. Wetzlar (*Arch. Eisenh.*, 1959, **30**, July, 429–434) Degree of stabilization of 16%Cr–16%Ni steels containing Nb is clearly detectable in the course of precipitation both in the presence and absence of Mo. In both cases slight understabilization leads to persisting Cr carbide precipitation. The effects of over and understabilization on the formation of intermetallic compounds, and the influence of creep tests at 700° and 650°C are discussed (20 refs).

Kinetics of the first stage of graphitisation of malleable cast iron S. Drápal (*Hutn. Listy*, 1959, **14**, (6), 501–507) Experiments carried out by the author on the isothermal decomposition of ledeburitic cementite are described, and problems relating to the formation and growth of graphite nuclei are discussed (39 refs).

Diffractometric study on formation of ferrite in cold worked 18–8 stainless steel G. Shinoda and T. Kawasaki (*Osaka Univ., Fac. Eng. Techn. Rep.*, 1958, **8**, Oct., 363–371) The amount of ferrite produced by transformation from austenite by cold working was determined with an accuracy of 0·1% by comparing line intensities due to each constituent with those of standard samples. Ferrite almost disappears after 40 min annealing at 600°C, and none was detected when the specimen was strained above 400°C.

The kinetics of ferrite formation during the decarburizing of carbon and alloy steels A. A. Ponov and M. S. Mikhalev (*Fiz. Met.*, 1959, **7**, (2), 198–208) For given temp. and periods of exposure to heat, an increase in the original carbon content increases the quantity of carbon burned off but decreases the depth of the pure ferrite layer. The total depth of the decarburized layer hardly depends on the original carbon content. With equal times of exposure to heat an increase in the temperature of decarburizing results in an increase in the quantity of burned-off carbon and in an increase in the total depth of the decarburized layer. The depth of the deposited layer of pure ferrite increases initially, reaches a maximum and then decreases tending to zero, as the temperature nears that of the A_3 point for iron or the $\alpha \rightleftarrows \gamma$ transformation for the decarburized alloy with the same alloy elements.

On the decay of the residual austenite in R 18 high speed steel S. N. Krasotskaya and B. A. Anaev (*Fiz. Met.*, 1959, **7**, (2), 192–197) A comparison between the kinetics of breakdown of residual austenite during tempering in R 18 steel and those of steels containing the same amount of alloy elements as the high speed steels, shows that on alloying the steel with W and Cr, the austenite decay proceeds in the same way as in the R 18 steel. V gives different results. It follows that the austenite decay in high speed steels is conditioned by the influence of Cr and W. Cr tends to increase considerably the strength of the residual austenite.

The use of statistical methods in the study of the decomposition of austenite J. Likeš, K. Mazaneč, and J. Cadek (*Hutn. Listy*, 1959, **14**, (3), 215–222) [In Czech] The application of statistical methods in nucleation and growth problems is discussed.—P. F.

Sub-zero treatment of quenched steel. I. On the stabilization of retained austenite Y. Imai and M. Izumiyama (*Sci. Rep. Res. Inst. Tohoku Univ.*, 1958, **A10**, Dec., 414–425) [In English] Ageing promotes the stabilization of retained austenite and increases the martensitic transformation rate on sub-zero cooling; with increased ageing a max. occurs in the martensite transformation rate. The transformation caused by sub-zero cooling exhibited 'burst' characteristics when ageing increased to a certain amount. The stabilization of austenite is caused by a mechanism similar to age-hardening (34 refs).—K. E. J.

Retained austenite in precipitation hardening stainless steels G. Krauss jun. and B. L. Averbach (*Trans. ASM*, 1959, **52**, preprint 134, 25) X-Ray diffraction studies of retained austenite in 17 Cr–7 Ni–1 Al and 17 Cr–4 Ni–3 Mo alloys after various heat treatments are reported. The amount was quite high after solution treatments (60–80%) but subsequent treatments reduced these to 7–10%. Martensite formation on cooling appears to be the primary mechanism of hardening in the latter alloy.

The effect of heat-treatment on the structure of bainite, particularly in cast iron J. Thieme (*Giesserei, Tech.-wiss. Beih.*, 1959, (23), 1277–1284) Bainite formation is reviewed and the results obtained on two cast irons are reported in which bainite formation was induced by (*a*) isothermal heat-treatment (in the absence of alloying elements) and (*b*) by high alloy addition and normal cooling rates. The mechanism of bainite formation is explained and its effects on industrial production discussed.—T. G.

The martensite transformation in thin foils of iron–nitrogen alloys W. Pitsch (*Phil. Mag.*, 1959, **4**, May, 577–584) In thin foils thin fibre crystals form with twin orientation different from the form of all bulk materials. A simple mechanism of distortion and a half twin shear is advanced.

Some aspects of the formation of martensite R. Kumar (*Trans. Indian Inst. Met.*, 1958, **11**, Dec., 21–35) The general characteristics of martensite formation and kinetics of the free energy change theories are reviewed (54 refs).

Mathematical description of the orientation relationship between martensite and austenite in iron–nickel single crystals A. Kochendörfer and G. Otto (*Arch. Eisenh.*, 1959, **30**, April, 227–232) Calculation of the orientation relationship between the martensite and austenite lattices is carried out, with reference to the investigations on Fe–Ni single crystals already reported by the above authors (*ibid.*, 1958, **29**, 709–714, 775–784). The matrix for the observed relationship differs from the relationships reported by Kurdjunow–Sachs and by Nashijama. It was found that the positions, calculated from the matrix of the positions of the martensite axes of rotation with given austenitic axes of rotation agreed with the observed positions for the existing four to five arrays (17 refs).

The free energy changes attending the martensitic transformation in the iron–chromium and iron–chromium–nickel systems L. Kaufman (*Trans. Met. Soc. AIME*, 1959, **215**, April, 218–223) An equation relating free energy difference to temp. and composition is obtained and used to calculate the free energy difference at the Ms point for low-C stainless steels. An explanation is also advanced for the anomalous effect of Cr in forming a γ-loop concurrent with the lowering of Ms in iron-base alloys.

Martensitic structure inclusions in drawn steel wires Z. Steininger and J. Binder (*Hutnik* 1958, **25**, (9), 357–359) A description is given of experiments conducted on production specimens in the laboratory of the rod and wire works at Zabrze to reveal accumulations of martensitic structure in steel wire. Microstructures show the formation of martensite in wires and concrete reinforcement rods. The micro-hardness tests also showed the martensite to have a hardness of 1080 kg/mm² by comparison with that of the surrounding sorbite (560 kg/mm²).—M. T.

Phase analysis of heat-resistant constructional steels M. F. Alekseenko, N. F. Lashko, N. M. Popova, and G. N. Orekhov (*Metallov. Obra. Met.*, 9159, (5), 52–54) Steels 30Kh3VA, 30Kh2N2VA, and EI415 were compared after quenching and tempering and carbides were separated and analysed for Fe, Cr, Mn, W, V, and Mo. Tests for sustained strength at 550°C were carried out and related to the carbide constituents.

On the chemical nature of the intercrystalline phase in transformer steels A. G. Loshkarev (*Fiz. Met.*, 1959, **7**, (2), 311–312) Experiments have shown that the intercrystalline phase of transformer steels contains an iron silicide Fe_2Si. It must be emphasized that iron silicide always forms with Si contents up to 20%, but that the intercrystalline phase forms mainly during appropriate heat treatment.

On the nature of the mechanism of formation of surface layers on carbon steels with arsenic admixtures P. I. Kuleshov and I. I. Chaika (*Fiz. Met.*, 1959, **7**, (1), 91–94) The thin surface layer forming on carbon steels containing arsenic in high-temp. oxidation is a solid solution of As in ferrite. The arsenic-ferrite layer forms because of the accumulation of As in the thin austenite layer adjoining the scale, following phase crystallization.

A new silicide in a 12% chromium steel H. Hughes (*Nature*, 1959, **183**, May 30, 1543–1544) A new phase, called the *H*-phase, is reported in a steel with 0·098%C, 3·18%Mn, 3·02%Si, 4·06%Ni, 12·56%Cr, 0·49%Mo, and 1·09%V. It has not, so far, been separated from the $M_{23}C_6$ phase but appears to be a silicide.

Investigation on the ternary system iron–molybdenum–oxygen W. Jager, A. Rahmel, and K. Becker (*Arch. Eisenh.*, 1959, **30**, July, 435–439) Radiographic examination showed the presence of the compounds Fe_2MoO_4 and $Fe_2(MoO_4)_3$, which have not previously been described, and confirmed the presence of the known compounds $FeMoO_4$ and $Fe_4Mo_8O_{31}$. Phase diagrams were established for the systems Fe_2O_3–MoO_3, $FeMoO_4$–MoO_3, and $FeMoO_4$–$Fe_2(MoO_4)_3$, and the system FeO–MoO_3 was investigated radiographically.

Equilibrium adjustments in the ternary system iron–cobalt–chromium W. Köster and G. Hofmann (*Arch. Eisenh.*, 1959, **30**, April, 249–251) The isothermal sections for 600° and 700°C of the Fe–Co–Cr system are worked out after an anneal of up to 1000 h. The compositions of the α- and γ-solid solutions in the resulting equilibrium condition differ widely from the proportions found after short-time heat treatment.

The boundary surface iron–lead E. Pelzel (*Metall.*, 1959, **13**, June, 552–554) The relationship of wettability and adherence at the solid–liquid interface of a binary alloy is discussed, and experiments are described which show the increased adherence at higher temperatures of a Pb–Fe boundary surface. The effects of additions of Sn and Sb to the Pb are described.

CORROSION

Documentation in the field of corrosion W. Wiederholt (*Werkstoffe Korros.*, 1959, **10,** June, 363–372) Literature classification systems developed by NACE, ASM, SLA, and DK are compared, and a system drawn up to suit the requirements of the corrosion industries is described.

Classification of topics relating to corrosion D. M. Brasher (*Corrosion*, 1959, **15,** May, 254t–256t) The classification system developed at the Chemical Research Laboratory – [Now the National Chemical Laboratory] – for compiling a complete corrosion bibliography and for recording and indexing technical enquiries is described. It is based on the NACE Abstract Filing Index with expansion and rearrangement. Examples of the use of the classification and its index are given.—J.F.S.

Contribution to the problems of the kinetics of metal dissolution I. Sekerka and G. W. Akimov (*Werkstoffe Korros.*, 1959, **10,** June, 383–385) Activation energy values for several metals (including Fe) in concentration ranges 0·1N, 0·1–0·5N, and >0·5N H_2SO_4, HCl, NaOH, and NH_4OH.

Impressions of Russian corrosion research J. B. Cotton and E. C. Potter (*Corros. Techn.*, 1959, **6,** April, 117–118) A report on a conference in Moscow in May 1958.

Influence of temperature on corrosion fatigue. I. I. Cornet and S. Golan (*Corrosion*, 1959, **15,** May, 262t–268t) The effect of temperature between 80° and 180°F on the resistance of two carbon steels to corrosion fatigue has been studied. Cold-drawn drill-rod wire was bent using a rotating wire arc fatigue machine and immersed in 2·5%NaCl. Oxygen concentration in the solution had little effect but it is postulated that the rate of oxygen diffusion to the steel controlled the type of pitting developed and hence the corrosion fatigue life. Under the experimental condition described, increased temperature led to increased corrosion fatigue life. The apparatus is recommended for general corrosion fatigue studies.—J.F.S.

Reaction mechanisms of atmospheric corrosion of metals in moist air contaminated with sulphur dioxide K. Barton and E. Beranek (*Werkstoffe Korros.*, 1959, **10,** June, 377–383) Experiments are described in which the mechanism of the formation of solid reaction products on Fe and non-ferrous metals by the action of moist air containing SO_2 is investigated (14 refs).

The problem of pitting corrosion in austenitic Cr–Ni steels H. Gräfen (*Metalloberfläche*, 1959, **13,** June, 161–166) In order to investigate the cause of this type of corrosion, tests were carried out in $MgCl_2$ solution at 80°C, with various additions, and potential-time and current-potential curves were derived for various media. The most pronounced effects were obtained with solutions containing halogen ions plus redox systems with reducible cations (10 refs).

Corrosion of steel in concrete A. Bäumel and H.-J. Engell (*Arch. Eisenh.*, 1959, **30,** July, 417–428) After showing that the corrosion behaviour of steel in concrete is simulated by steel electrodes embedded in sand which is soaked in 0·1N NaOH or saturated $Ca(OH)_2$, in both of which solutions steel is passive, the effect of adding Cl ions to these electrolytes was observed by means of current density-potential curves. As little as 0·0035%$CaCl_2$ destroyed the passive layer.

Solving some oil ash corrosion problems R. S. Norris (*Corrosion*, 1959, **15,** May, *Technical Topics*, 126–129) Corrosion problems caused by deposits from oil-fired burners are discussed and in particular the role of V in the ash is explained. Possible remedies are described with emphasis on a liquid oil-soluble additive containing a high proportion of metallic compounds designed to raise the melting point of the vanadates in the ash.—J.F.S.

Studies of the corrosion behaviour of non-drying oils and greases with special reference to modern lubricants and rust preventatives for metals A. Bukowiecki (*Schweiz. Arch. Wiss. Techn.*, 1959, **25,** Jan., 23–24; Feb., 62–74; March, 96–101) This section deals with the corrosive action of hot sulphur-bearing oils on Cu, and corrosion tests in gear oils and hot automobile lubricating oils. The corrosion behaviour of non-drying oils and greases high in water and salts is examined in the light of published material and experiments carried out by the author. Another section deals with the protection of metals against corrosion by thin layers of non-drying oils and greases. Some factors in the inhibiting action of these substances are discussed, with reference to data given in the literature.

Corrosion of refinery equipment by aqueous hydrogen sulphide R. V. Comeaux (*Corrosion*, 1959, **15,** April, 189t–193t) A discussion of the corrosion problems associated with the occurrence of H_2S in the presence of water below 400°F is followed by a theoretical discussion. The avoidance of high velocity, low pH exposures should control corrosion. Corrective measures in current use in oil refineries are described. An analysis of the failure of several steel-tubed heat exchangers is discussed with emphasis on possible improvements in design and materials of construction. Zinc or aluminium coatings on steel may be useful in these conditions.—J.F.S.

Corrosion problems associated with uranium refining F. H. Meyer jun., F. L. Podlipec, and T. R. Kato (*Corrosion*, 1959, **15,** April, 168t–170t) The corrosion problems of the uranium refining industry are reviewed with special reference to the materials of construction, chiefly stainless steels, used for the reaction vessels and ancillary equipment. Alternative materials are discussed.—J.F.S.

Visual observations on the water stream in an elevated temperature high velocity loop R. E. Seebold (*Corrosion*, 1959, **15,** April, 183t–184t) An apparatus is described for examining the corrosion occurring inside a high temperature–high velocity water loop by visual means. The Tyndall effect was used to estimate the quantity of corrosion product suspended in the water. The addition of oxygen inhibited the corrosion process.—J.F.S.

Corrosion of steels in liquid bismuth and lead J. A. James and J. Trotman (*JISI*, 1960, **194,** March, 319–323) [This issue].

Erosion of materials by cavitation attack D. Peckner (*Corrosion*, 1959, **15,** May, 269t–274t) Causes and possible mechanisms of cavitation attack are related to erosion and discussed. Streamlining, good surface finish, and the use of resistant materials can all reduce cavitation attack. Methods of assessing cavitation resistance of materials in the laboratory are discussed. A 2-h magnetostrictive test can be used to compare materials. Data are included on the effect of hardness of Cr stainless steels on their performance in the accelerated cavitation test and on the effect of inhibitors on resistance to pitting in the same test. Several cast brasses, monels, irons, and stainless steels are compared by the method.

Structure of scale on plain carbon steels S. Garber (*Nature*, 1959, **183,** May 16, 1387–1388) Products from continuous rod and strip mills showed a magnetite–wustite–magnetite structure, sometimes with a thin outer layer of haematite. The mechanism of formation is discussed.

On the equilibrium of ferrous oxide with iron and the formation of nuclei at the metal surface in hydrogen–water vapour mixtures at elevated temperatures D. Fuller-Brain and J. Bardolle (*Compt. Rend.*, 1959, **249,** July 6, 120–122) Iron purified by zone melting was used heated in H_2 at 850°C for some hours and polished first with emery and diamond and then electrolytically. They were heated in dry H_2 at 890°C for 24 h and cooled in the same atmosphere. Moist H_2 was then introduced after raising to the required temp. and nucleation was estimated microscopically. The results of Chaudron were generally confirmed.

The scaling of pure iron–silicon alloys in oxygen in the α-region N. G. Schmahl, H. Baumann, and H. Schenck (*Arch. Eisenh.*, 1959, **30,** July, 415–416) Continuing experiments on the scaling of pure Fe–Si alloys at 950° and 1050°C reported in an earlier paper (*ibid.*, 1959, **30,** 267–273), alloys containing 0·03–3·63%Si were investigated at 890°C, a temperature at which only α-phase is formed in this range of alloys. The kinetics of the scaling process at this temperature are compared with those in Fe–Si alloys which lie in the α- or γ-region according to temperature or Si content.

Oxidation studies on the iron–chromium–aluminium heater alloys E. A. Gulbransen and K. F. Andrew (*J. Electrochem. Soc.*, 1959, **106,** April, 294–302) Three alloys were studied and weight gain methods were used, the structure and composition of the films being determined by X-ray diffraction. Adhesion properties were measured by straining during oxidation. A change in rate was observed near 900°C with a constant rate from 900–1050°C and an increase at higher temperatures. A crystal structure change appeared to be responsible. At 1050°C the main oxide present was α-Al_2O_3. Interpretations of the kinetics are given and the results are correlated with practical performances.

Investigation of Fe–Mn–Cr–N–C system for heat resistance and oxidation resistance between 1200 and 2000°F J. P. Tarwater and E. J. Dulis (*WADC Techn. Rep.* 57–242, *ASTIA Document No.*203523; *PB* 151558, 1958, Oct., 103) Austenitic Cr–Mn–C–N steels with various combinations of V, Nb, W, and Mo had tensile and creep properties comparing favourably with super-alloys such as A286 and Inco 901. Addition of Ca improved creep-rupture strength in the absence of V, Nb, Mo, and W, and about 2%Si increased oxidation resistance to that of 310 stainless. These steels can be hot-rolled.

Corrosion rate measurement by hydrogen effusion in dynamic aqueous systems at elevated temperature and pressure M. Krulfeld, M. C. Bloom, R. E. Seebold (*Corrosion*, 1959, **15,** April, 179t–182t) A method is described for using the H_2 effused through a section of a pipe wall as a measure of the corrosion rate inside the pipe. Details are given of the reproducibility obtained in low carbon steel systems at a flow velocity of 1 ft/sec at 600°F and 2000 psi. A quantitative comparison is made with a static system at this temperature and pressure. Some observations at 30 ft/sec flow velocity are included and lead to a discussion of the corrosion at high and low flow rates. Corroding specimens inside a pipe could be detected indicating high local sensitivity of the method. Difficulties involved are also considered.

Laboratory methods for determining corrosion rates under heat flux conditions A. O. Fisher and F. L. Whitney jun. (*Corrosion*, 1959, **15,** May, 257t–261t) Laboratory experiments have indicated that skin temperature, rather than heat flux, controls corrosion rates of mild and stainless steel and cast iron used for heat transfer surfaces in several acid media. The design of a suitable laboratory apparatus to measure corrosion rates under these conditions is examplified.—J.F.S.

Autoclave testing of type 304 stainless steel J. F. O'Brien and L. E. Phillips (*PB* 151149, 1958, May, 54) U-bend test specimens were tested in corrosive solutions in a rocking autoclave. Careful control of atmosphere gave reproducible results and cracking depended upon O_2 and Cl-ion concentrations. The oxide film was sometimes sufficient to induce cracking even with low O_2 content but in general without 4% O_2 cracking did not occur.

Autoclave testing of type 430 stainless steel J. W. McGrew (*MND–E–1602*, 1959, Jan., 25; from *Nuclear Sci., Abst.* April 15, 613) U-bend specimens were not susceptible to stress corrosion cracking in 100%O_2, in up to 1100 ppm chloride at pH 11·5 at 400°F for up to 1176 h in a rocker-type autoclave, nor did it occur in $MgCl_2$ solution. Pitting corrosion might occur with >100 ppm chloride and 20%O_2. Croloy 16–1, with higher Ni, resisted these conditions. Stress corrosion at low pH has been observed previously.

Usefulness of cold probe corrosion test in evaluating fuel treatments H. N. Wigan (*Chem. Age*, 1959, **81,** May 23, 862) An account of the control of corrosion in the burning of S-bearing fuels in boilers with a note on the water-cooled probe method of testing.

Study of chemical factors affecting corrosion of carbon steel AISI 1020 by liquid-phase fuming nitric acid J. B. Rittenhouse and D. M. Mason (*Corrosion*, 1959, **15,** May, 245t–250t) Corrosion rates of cold reduced and annealed plain carbon steel tubing in fuming nitric acid

were obtained by measuring the change in electrical resistance of the tube with time. Corrosion rates decreased as the NO_2 concentration increased from 0 to 14% w/w or as the H_2O content increased from 0 to 3·5% w/w. Nitronium ion (NO_2^+) or nitrogen pentoxide may thus be involved in the rate-controlling step. Short-term passivation was obtained with NO_2 concentrations above 9% and H_2O at about 3·5%, or when a suitable oxide film was initially present on the steel. Perchloric, sulphuric, or hydrofluoric acid additions also gave short-term inhibition.

Criticism of the method of testing chemically resistant steels in concentrated boiling nitric acid H. Zitter (*Werks. Corr.*, 1959, **10**, May, 311–321) It is shown by reference to the published literature that the boiling HNO_3 test is not reliable as a guide to the corrosion-resistant properties of chemically-resistant steels in other media. More reliable information can be obtained by examination of the structure; tests in corrosive liquids are reliable only if such liquids are to be used in practice (31 refs).

The effect of sigma phase vs. chromium carbides on the intergranular corrosion of type 316 and 316L stainless steel. Part I. A survey of the literature D. Warren (*Corrosion*, 1959, **15**, April, 213t–220t) A detailed survey of the literature on the intergranular corrosion of stainless steels is given to determine the relative effects of Cr carbides and σ-phase. Eight acids can cause intergranular corrosion of austenitic stainless steel if a continuous carbide network is present: acetic, HF, HCl, lactic, HNO_3, H_3PO_4, H_2SO_3, and H_2SO_4. Only limited information of the effect of σ-phase is available. **Part 2. Laboratory investigation** (May, 221t–232t) Two Ni–Cr–Mo stainless steels were compared in laboratory studies for their susceptibility to intergranular attack in HNO_3, HNO_3–HF, acetic, citric, sulphuric, lactic, oxalic, formic, and phosphoric acids. The lower carbon type was relatively free from carbide precipitation but had an increased tendency to form σ-phase as a continuous network in the grain boundaries when sensitized. Yet this steel had excellent resistance to intergranular attack in all acids except nitric. The higher carbon type having a continuous grain boundary network of chromium carbide underwent severe intergranular attack in twelve of the fourteen acids. The use and limitations of the standard nitric acid test are briefly discussed.—J.F.S.

Electrochemical aspects of stress corrosion D. K. Priest (*J. Electrochem. Soc.*, 1959, **106**, April, 358–360) Evidence for the electrochemical rather than any mechanical mechanism of stress corrosion is advanced.

Corrosion (*Arthur D. Little Res. Inst. Ann. Rep.*, 1958, 11–13) Tests on organic inhibitors and controlled atmosphere studies are briefly referred to.

The corrosion inhibiting and wear-reducing action of zinc dithiophosphates in modern motor oils R. Larson (*Schweiz. Arch. Wiss. Techn.*, 1959, **25**, Feb., 54–61) The mechanism of the action of Zn dithiophosphates as anti-oxidants, inhibitors of bearing metal corrosion and of corrosive and abrasive wear in automobile engine parts is discussed.

Selecting corrosion and scale inhibitors for cooling water H. Shields, L. V. Sorg, and R. L. Stutz (*Corrosion*, 1959, **15**, May, 233t–236t) The methods used for selecting corrosion inhibitors for refinery cooling water have included laboratory, pilot plant, small commercial cooling tower, and full scale plant tests. The small-scale work gave accurate forecasts of plant performance. Organic chromates proved best of 50 inhibitors tested in the river water used. Phosphates, although inhibiting corrosion, caused too much scaling at low pH. Metal penetration rates and scale deposition data are given.—J.F.S.

Comparative investigation of the corrosion protective action of zinc, cadmium and tin coatings on steel H. W. Dettner (*Werks. Corr.*, 1959, **10**, May, 321–326) Comparative tests on electrolytic coatings of Zn, Cd, and Sn deposited under various conditions, with or without intermediate coatings of Cu or Ni are described; tests were made by spraying with brine, and by subjecting to industrial atmospheres and climatic influence. The results are tabulated (10 refs).

Internal cathodic protection. 2. The application of cathodic protection to the inner walls of a rectangular box C. Plumpton and C. Wilson (*Corros. Prev.*, 1959, **6**, March, 49–54) After pointing out that many industrial anti-corrosion problems involve rectangular tanks, a detailed mathematical treatment is given of the application of cathodic protection by means of a number of anodes.

New results on the investigation and prevention of boiler corrosion K. Kovács (*Metalloberfläche*, 1959, **13**, June, 167–168) Results obtained under industrial conditions are classified, and the main causes of chemical and electrochemical corrosion processes, conditions leading to dangerous corrosion and the relationship between local overheating of tube walls and local corrosion discussed.

Corrosion protection of steel structures in contact with water by means of flame-sprayed zinc coatings Z. Kowalski (*Werkstoffe Korros.*, 1959, **10**, June, 357–363) The application of flame sprayed Zn coatings to steel structures in contact with water is discussed, with particular reference to Polish experience (23 refs).

Cathodic or electrochemical protection against rust? H. Hebberling (*Werkstoffe Korros.* 1959, **10**, June, 376–377) The advantages and limitations of cathodic protection and protective coatings, with or without electrochemical action are discussed.

Corrosion protection methods in light-oil tankers R. H. Maass and R. D. Merrick (*Werks. Corr.*, 1959, **10**, May, 305–311) Methods developed by Esso Research and Engineering Co. in co-operation with Esso Shipping Co. for protection against corrosion by refined oils are described; these include inhibiting films, cathodic protection, paints, and the use of low-alloy steels.

Corrosion prevention in tankers and storage tanks by fogging or flotation with an inhibitor solution J. C. D. Oosterhout, M. E. Stanley, and W. S. Quimby (*Corrosion*, 1959, **15**, May, 241t–244t) Two methods have been developed for protecting the internal surfaces of ballast tanks. Fogging uses a fine mist of inhibitor solution which coats the walls and underdeck area of the tank before filling. Flotation uses a small quantity of inhibitor floating on the ballast and involves completely filling the tank temporarily with ballast in order to coat the underdeck areas. Both proved highly effective but fogging is cheaper. Details of the most effective procedures are given.—J.F.S.

ANALYSIS

Rapid analysis of iron and steel S. N. Chrobok and E. Beaver (*Eng. Found.*, 1959, **24**, May, 39–43, discussion 44–46) An outline of rapid spectrophotometric methods is given.

Contributions to the chemistry of iron and steel: Analysis of pig and cast iron (1953–1958) H. Bockshammer (*Stahl Eisen*, 1959, **79**, Sept. 17, 1370–1371) A review of the literature on the analytical chemistry of pig and cast iron dealing with: estimation of C, S, and P, P and Si, also of As, Al, Mg, N_2, a number of impurities, and of Mo, Pb, Na, and Te (29 refs).

Some aspects of potentiometric titrations in alloy analysis D. R. W. McLaren (*Metallurgia*, 1959, **59**, May, 257–261) Potentiometric titration theory is discussed with reference to oxidation-reduction titrations, where cells using a reference calomel electrode and those using polarized Pt electrodes are employed.

Rapid methods of analysis of metals and ores VII. Polarographic determination of cerium in alloys and minerals J. Doležal and J. Novak (*Coll. Czechoslovak Chem. Comm.*, 1959, **24**, July, 2291–2298) [In German] Use of a K_2CO_3 or a (K Na) tartrate solution gives an accuracy of ±1%Ce in Fe or Zn and lower precision in Al, Ni, or V. Other rare earths do not interfere. Analyses of Ce, gas mantles, alloys, and monazite sand are given.

A rotary sampling machine for the sampling of cast iron H. Green (*BCIRA J. Res. Dev.*, 1959, **7**, April, 644–650) Tests with the sampler described show that it gives representative samples of cast iron (white, grey, or nodular) particularly suitable for C and S determinations.—A.G.

Apparatus for carbon content determination R. Rew (*BCIRA J. Res. Dev.*, 1959, **7**, April, 651–655) Features of apparatus and layout of the carbon assay room of the BCIRA laboratory are described.—A.G.

Contribution to the problems involved in the determination of oxygen from the nonmetallic inclusion content in rimming steels A. Šmrhová and J. Janaček (*Hutn. Listy*, 1959, **14**, (6), 559–564) Comparative analysis by electrolytic isolation of inclusions and by vacuum fusion showed good agreement in the outer regions of a 3·7 t cogged mild steel rimming ingot, but vacuum fusion gave higher results in the centre of the bloom.

Determination of total hydrogen contents in weld metal (*Brit. Weld. J.*, 1959, **6**, Feb., 87–89) A tentative recommendation for the determination of total H_2 content in single beads of weld metal is made.—A.D.H.

The coulometric determination of sulphur in silicon-iron L. E. Hibbs and D. H. Wilkins (*Anal. Chim. Acta.*, 1959, **20**, April, 344–352) A rapid and accurate method is described suitaboe for the determination of sulphur in concentrations less than 0·01% in metallurgical materials, particularly Si-iron.

The chelometric determination of chromium, cobalt (III) and copper with a metalfluorochromic indicator D. H. Wilkins (*Anal. Chim. Acta*, 1959, **20**, April, 324–325) Amounts of Cr, Co^{3+}, and Cu of the order of 20–60 mg were back-titrated with standard Cu after adding excess EDTA, using calcein as a fluorescent indicator.

Titrimetric determination of manganese after its oxidation to the tervalent state I. G. Ryss and B. S. Vitukhnovskaya (*Zhur. Anal. Khim.*, 1959, **14**, (3), 318–321) Quantitative oxidation of Mn^{++} to fluoromanganate by heating with NH_4NO_3 and HF followed by iodimetry or titration with ferrous ammonium sulphate using diphenylamine is described. Fe, Cr, Co, and Ni salts do not prevent the oxidation. The method is suggested for analysis of Fe–Mn.

Photocolorimetric determination of vanadium as the phospho-vanado-tungstic complex: application to steel analysis C. Foucart and C. Vandael (*ATB Métallurgie*, 1956, **1**, (2), 55–61) A difference method is described for the photocolorimetric determination of V (0·02–0·36%) in the presence of 3%Ni, 2·5%Cr, and 1·5%Mo. Preliminary separation is necessary for 18/8 steels and steels containing W.

Rapid analytical methods for the investigation of metals and inorganic raw materials. X. Use of ion exchangers in the determination of manganese and alkaline aerths P. Povondra and Z. Šulcek (*Coll. Czechoslovak Chem. Comm.*, 1959, **24**, July, 2398–2404) [In German] Strongly acid Amberlite 1R–120 is used, followed by elution with EDTA solution.

Comparative analysis between various methods of copper determination in iron and steel H. Pohl (*Materialprüfung. Materials Testing, Materiaux Essai et Recherches*, 1959, **1**, May, 20 177–178) A comparison of the gravimetric salicyldioxime separation method and the photometric Cu carbamate extraction method show them to give equally good accuracy and reproducibility. The advantages of the photometric method are pointed out.

Polarographic determination of Cu, Pb, Bi and Fe in stannous sulphate H. Kato and S. Nagamura (*Toyo Kohan*, 1956, **4**, Dec., 25–29) The solution used for electrolytic tinplate in the Ferrostan process is based on $SnSO_4$. This is decomposed to oxide at 500–600°C and extracted with a dilute acid (HNO_3) and satisfactory analyses can be made for the impurities.

Half-wave potentials of metal ions in organic hydroxyacid supporting electrodes. II. S. Baumgarten, R. E. Cover, H. Hofsass, S. Karp, P. B. Pinches, and L. Meites (*Anal. Chim. Acta*, 1959, **20**, April, 397–404) The polarographic characteristics of most of the heavy metal ions in ammoniacal solutions of ammonium citrate, malonate, oxalate, and tartrate are tabulated (15 refs).

Recording spectrometers. III. P. W. J. M. Boumans (*Chem. Weekb.*, 1959, **55**, July 18, 375–377) Attention is called to the difficulty with twin cell methods of applying the two

photocells and also the two amplifiers. It is suggested that the problem is surmountable by using only one photocell with an amplifier. Mechanical means of interrupting the rays need them to be adopted in order to be able to distinguish them from one another. A circuit for providing electrical and optical compensation is shown and then the article goes on to deal with the relative merits of the different types of spectrometer available on the market. These include the Perkin-Elmer, Unicam, Leitz, and Beckman IR-4 models which use optical compensation and the Beckman DK, de Cary 14 and 14 and the Zeiss RPQ 20A models which use electrical compensation. Impulse, phase, and frequency separation are also discussed.—F.R.H.

Spectrochemical analysis by scanning R. Breckpot, M. D. E. Jonckers, and A. Daniels (*ATB Métallurgie*, 1957, **1**, (4), 110–114) A direct-reading high-dispersion prism instrument with a scanning slit is used for the analysis of pig iron and Thomas steels for C, Mn, Si, and P. Tables showing the reproducibility of the results are given. A Philips universal multisource was used, with ac spark excitation for C and Mn, and a dc arc for P and Si.

Experiences with direct recording spectrographs in the ironworks laboratory. 1st report A. Pack and B. Zischa (*Arch. Eisenh.*, 1959, **30**, July, 407–410) Si and Mn are determined in pig and mixed iron by means of a spectrograph-photoelectrometer combination. The design of sample mould, and the use of the instrument for control tests are described.

A discussion of the slope of the calibration curve in spectrochemical analysis Hsu Shengmei and Ho I-djen (*Acta Physica Sinica*, 1959, **15**, (4), 178–185) Si, Ni, and Co multiplets are analysed for concentration and intensity effects.

Universal methods for the spectrochemical analysis of alloy steels Ren Ta-kang, Han Thang-yu, Yu Po, Chang Kung-soo, and Wang Hung-chang (*Acta Physica Sinica*, 1959, **15**, (4), 173–177) A standardized method of solution preparation for analysis on carbon electrodes and a powder method for oxides for the ac arc are described.

Simultaneous spectrophotometric determination of traces of cobalt, nickel and copper with dithio-oxamide W. D. Jacobs and J. H. Yoe (*Anal. Chim. Acta*, 1959, **20**, April, 337–339) The complexes of Co, Ni, and Cu with dithio-oxamide are examined, and a spectrophotometric method for their simultaneous determination is described, absorbance being measured at 440, 640, and 385 mμ, and the respective concentrations determined from three spectrophotometric equations.

Effect of carbon on the spectrochemical analysis of chromium steels Chang Kung-soo and Ho I-djen (*Acta Met. Sin.*, 1959, **4**, March, 87–91) [In Chinese] In high-Cr steels, carbon interferes when present in solid solution and at higher contents than 1%. Its presence affects volatilization from the solid electrodes, this being marked with Cr. The Fe–C–Cr bond may thus be stronger than the Fe–C–Fe bond.

Spectrographic analysis of small amounts of rare earths in alloy steel Li Shuh-cho and Wang Yü-me (*Acta Met. Sin.*, 1959, **4**, March, 81–86) [In Chinese] Direct spectrography is impossible because of interference by tin lines. The rare earths must first be concentrated by mercury cathode separation and ether extraction. Yt or Th is used as carrier and internal standard. A carbon arc is used. As little as 50 μg of total rare earths in a 1-g sample of steel can be determined within ±10%.

Determination of boron in steel and iron by the aluminium spark method Wang Hong-jang (*Acta Met. Sin.*, 1959, **4**, March, 75–80) [In Chinese] The sample is dissolved in $HClO_4$ without removing iron, some NaOH is added, and the solution is placed on an aluminium spark electrode (details given). The method is sensitive and precise; boron in the range 0·005–1·0% can be determined (12 refs).

Rapid method of determining the basicity of open-hearth slags H. vom Ende and F. Bardenheuer (*Arch. Eisenh.*, 1959, **30**, July, 391–396) Basicity is determined in 6 min by measuring the electrical resistance of aqueous slag suspensions; it is shown that the amount of lime to be added for a given degree of desulphurization can be calculated from the basicity of the initial bath sample.

Rapid determination of lime and magnesia in the slag of the basic electric furnace K. Sekimoto and K. Iwamoto (*Nihon Teppan*, 1959, **10**, March, 3–9) A rapid method for determining MgO and CaO in the slag depends on a chelate titration using a metallic indicator. Fe, Al, and Mn are not removed first. The method gives accurate and reproducible results with low MgO contents.—K.E.J.

INDUSTRIAL USES AND APPLICATIONS

Low-alloy heat-resisting steels for steam turbines R. Pokorný (*Hutník*, 1959, **9**, (5), 153–154) A new Cr–Ni–Mo–W–V steel 'Škoda T 56' containing a total of 3% of alloying elements was developed for use up to 570°C. The steel is of the ferritic-pearlitic type; it has a high creep resistance.—F.F.

Fastening steel for power-generating equipment with steam parameters of 140 atm, 570°C A. V. Ratner and A. S. Panicheva (*Metallov. Obra. Met.*, 1959, (3), 28–32) Pearlitic steels had to be developed for fasteners and fittings. A Cr–Mo steel was developed and tested after various heat treatments. Nitriding and boriding were also carried out. Strength, relaxation, and ageing tests up to 2000 h showed the steel to be suitable.

The role of tube thickness and thermal stresses in superheaters made in ferritic and austenitic steels N. Salier (*Rev. Univ. Min.*, 1959, **15**, July, 633–649) Taking thermal stresses into account, it is shown that increased wall thickness does not give improved life beyond a certain point. The high thermal stresses and residual stresses of austenitic steels are pointed out, and the advantages of ferritic steels are discussed.

Searching for new alloys suitable for steam and gas turbines R. P. Zaletaievová (*Hutnicke Aktuality*, 1958, **16**, 26–35) [In Czech] The development of austenitic, pearlitic, and semi-ferritic Cr steels for use at temp. above 600°C carried out at the Moscow Institute of Machine Design and Construction in recent years is discussed. The composition, heat-treatment, and properties of the various steels are given.—P.F.

Light sheet-metal containers W. Panknin (*Sheet Met. Ind.*, 1959, **36**, April, 257–267) An illustrated account of the manufacturing process and machinery for the production of cans.

Aircraft and missile problems spur successful Western metal congress (*Met. Prog.*, 1959, **75**, April, 96r–96N) An outline of the papers delivered at the Western Metal Congress held at Los Angeles in March 1959, and dealing with selection criteria of materials for aircraft frames, power plant, and missiles, with reference to high and low temperature work and fabricating, heat treatment, and inspection problems.

Steels for nuclear reactors C. V. Mills (*Iron Steel*, 1959, **32**, April, 149–153) The use of B steels, stainless, and mild low-Co and low-Mn steels and pressure vessel steels for nuclear reactor applications is reviewed.

Stainless steel made safer for atomic applications (*Steel*, 1959, **144**, April 13, 114, 118) The steel described is a very low carbon, Cr–Ni steel, AISI Type 304 L. By special control of raw materials and manufacture, Co is kept below 0·002% and cannot become a radioactive hazard in atomic applications.—A.G.

Development of iron-aluminium base alloy for gas-cooled reactor components F. Tate (*MND-DB-2524*, 1958, Dec., 49; from *Nuclear Sci. Abs.*, April 15, 613) The best alloy with regard to ductility and oxidation resistance is 7½%Al–5%Cr–3%Nb and 0·75–1·5%Zr. Alloy DB2 with 7%Al–5%Cr–½%Ti–1%Nb can be melted in air without change in tensile properties and a fine-grain structure can be obtained by pouring at ~2800°F into a cold mould. Hot-roll bonding and brazing techniques can be used.

An economic appraisal of stainless steel and zirconium in nuclear power reactors M. Benedict (*Met. Prog.*, 1959, **75**, Feb., 76–81) The low neutron-absorbing cross-section of Zr gives economic advantages over stainless steel as U of low enrichment may be employed in nuclear power reactors. On the other hand Zr costs very much more than stainless steel, i.e. the economic incentive to use Zr instead of stainless steel depends on the relative magnitudes of the resulting savings in fuel costs compared with its higher material cost. The economics with respect to the use of Zr or stainless steel were studied in five power-producing thermal reactors. The results are summarized.

Need [ed]: low-cobalt stainless for nuclear applications W. L. Fleischmann (*Iron Age*, 1959, **183**, Feb. 12, 106–107) The Co content of stainless steels is surveyed; very low values are often required for nuclear applications. Stainless steels commonly contain 0·02 to 0·2%Co. Values below 0·05 or even 0·01% can be maintained by selection of raw materials, particularly sources of Ni.—D.L.C.P.

Development of modern nuclear reactor materials with special reference to structural iron and steel H. Nakamura (*Tetsu to Hagane*, 1959, **45**, June, 627–639) [In Japanese] A review covering special steels etc. used in twelve British, American, Canadian, Russian, and German reactors.—K.E.J.

HISTORICAL

Ancient German settlement comprising a bloomery hearth and forge at Salzgitter-Lobmachtersen G. Stelzer (*Stahl Eisen*, 1959, **79**, Aug. 20, 1201–1206) The results of excavations in the Salzgitter district of Germany are reported. A very well preserved bloomery hearth was found as well as a number of steel forgings. The hearth is estimated to be of the second-century type. Non-ferrous metals were also manufactured at the site.—T.G.

An interesting example of early technology: a socketed axe from Wietrzno-Bobrka in the Carpathians J. Piaskowski (*JISI*, 1960, **194**, March, 336–340) [This issue].

Metallurgical interpretation of the excavated bloomery hearth, puddle steel, and slags at Salzgitter-Lobmachtersen B. Osann (*Stahl Eisen*, 1959, **79**, Aug. 20, 1206–1211).—T.G.

Iron smelting and processing at the Hohe Venn District during the Roman occupation A. Voigt (*Stahl Eisen*, 1959, **79**, Sept. 17, 1359–1361) An historical review.—T.G.

Guilds of the iron and steel trades F. W. Robins (*Edgar Allen News*, 1959, **38**, April, 87–89) A general account of the ancient smiths' guilds of Britain.

200th anniversary of Gutehoffnungshütte (*Iron Coal Trades Rev.*, 1959, **178**, May 15, 1131–1133) The history of the group is briefly given.

Steelmaking/U.S.A. L. F. Reinartz (*J. Metals*, 1959, **11**, May, 329–332) The second of a series of four articles on the history of steelmaking in the USA. Charging machines, tilting furnaces, and the early use of O_2 are included.

MISCELLANEOUS

Very small probes for flow measurements R. Ramshorn (*VDIZ*, 1959, **101**, July 11, 832–834) Four-fold probes with 2–3 mm dia. tubes for measuring the amount and direction of the velocity of air currents. In a specific range components of the direction of flow can be measured in two perpendicular planes without correction. Constructional details are given.

The production of metallic manganese from ore wastes Z. Kulinsky, B. Paczula, and K. Radzwicki (*Hutnik*, 1958, **25**, (11–12), 471–477) Three methods of production of metallic Mn are described – electro-thermal, alumino-thermal, and electrolytic – and the possibility of its production from slimes obtained during the production of vitamin C, chloromycetin and nicotinic acids. The experiments show that production by the alumino-thermic method is feasible under production conditions. Despite the high cost of granulated Al for reduction of the Mn oxides, Al is more efficient than Si, and the exothermic reaction in practice needs little heat to promote it (theoretically added heat is unnecessary). This was shown by the experiments to be the most satisfactory method, and the quality of Mn produced was high (96·9% pure). In 1959 the annual output of Mn slimes

from the production of vitamin C and chloromycetin in Poland is expected to be 1200 tonnes which could yield 240 tonnes metallic Mn. The cost (experimentally) was 34 464 zloty per tonne as against a world market price of $850 per tonne.—M. T.

A punched-card system for the control of breakdowns occurring in iron and steel works G. Kreyss and W. Trust (*Stahl Eisen*, 1959, **79**, Sept. 3, 1281–1285) A punched-card system is described that enables the maintenance engineer to control breakdowns in iron and steel works. A number of examples are quoted. In the discussion the merits of similar, but in some ways different, systems are advocated.

Automatic computing in the production departments of integrated iron and steel works H. Cordes (*Stahl Eisen*, 1959, **79**, Aug. 6, 1141–1144) Programming and automatic computing are explained and the equipment available described briefly. The usefulness of such a system to a continuous multi-stand cold rolling strip mill is discussed.—T. G.

Ways to success in metallurgical engineering as judged from the mechanical engineer's point of view W. Dehne (*Stahl Eisen*, 1959, **79**, Sept. 3, 1237–1243) The author compares the attitudes of the German and American maintenance engineer to his job in iron and steel works and stresses the superiority of the American concept. Planning and maintenance from this point of view are discussed in detail and it is emphasized that maintenance in German works should receive a higher priority than hitherto.—T. G.

Regulation technique E. Krochmann (*VDIZ* 1959, **101**, July 11, 835–844) A bibliography of literature appearing in 1957–59, classified into: mathematical and experimental investigations of control problems, methods of regulation, technique of control equipment and the structural elements, and applications of control to industry, including automation techniques (209 refs).

Meeting of the energy and management group (*Stahl Eisen*, 1959, **79**, Aug. 20, 1211–1215) A report on the meeting of the energy and management group celebrating its fortieth anniversary, with abstracts of the lectures delivered. The group is mainly concerned with heat and fuel economy and the general management problems in iron and steel works.

Production and financial planning as a tool of works management H. K. Vellguth (*Stahl Eisen*, 1959, **79**, Aug. 20, 1177–1183) The merits of planning are emphasized and the methods of arriving at conclusions are discussed.—T. G.

Biotechnological efficiency in an ironworks J. Pontén (*Tek. Tidsk.*, 1959, **89**, Feb. 27, 205–210) Problems relating to the connection between correct posture, as in the placing of a crane cab seat, and other working conditions on the workers' health and efficiency are discussed.

Organization of the department for optimum utilization of personnel in iron and steel works M. Forster (*Stahl Eisen*, 1959, **79**, Sept. 17, 1325–1334) The reasons why an iron and steel works should have a central department that controls and supplies the necessary personnel for the production sections are explained and the work of such a department is described.—T. G.

Are you safer with a safety officer? (*Safety*, 1959, May, 18–21) An account of a discussion. Whether the supervision should be delegated or placed in the hands of a specialist was considered.

Experiment at Consett R. Barry (*Safety*, 1959, May, 4–10). **Experiment at Shotton** (10–11) Schemes for accident prevention by Consett Iron and John Summers and Sons are outlined.

BOOK NOTICES

American Society of Mechanical Engineers, Battelle Memorial Institute. '*A Review of available information on Corrosion and Deposits in Coal- and Oil-fired Boilers and Gas Turbines*'. 11 × 8½ in., pp.viii + 198. Illustrated. 1959, New York, London: The Society; Pergamon Press (Price £2 10*s*.)

This valuable report by Battelle Memorial Institute was prepared on behalf of the ASME Research Committee on Corrosion and Deposits from Combustion Gases. British and German experience was included and use was made of numerous replies to a questionnaire sent to manufacturers of steam boilers and gas turbines and to electricity supply authorities. The report is composed of contributions from eight authors. After a general introduction, the first chapter is concerned with the mineral constituents in coal and heavy fuel oil and their behaviour during combustion. The next chapter deals with SO_2 and SO_3, and is followed by a chapter on the physical aspects of deposition. The fourth chapter is devoted to the origin and composition of deposits and to methods of minimizing them. Next follows a review of high temperature corrosion effects, a chapter on the corrosion of metals exposed to combustion gases below 400°F and finally, a seventh chapter on the removal of solids from combustion gases. Each chapter has a summary and references.

'*Basic Electronics*'. In six parts. 9¾ × 6 in., pp.111, 110, 100, 95, 92, 127. Illustrated. 1959, New York, London: The Brolet Press; The Technical Press Ltd. (Price, 12*s*. 6*d*. a part or £3 6*s*. a set.)

Like the earlier set of Manuals on Basic Electricity from which they lead on, these instruction books in Elementary Electronics were prepared for the United States Navy and have been adapted for use in the British Army. They are profusely illustrated, often with 'cartoon-type' drawings and the approach is completely non-mathematical and 'simplified'.

The British Steel Castings Research Association. '*British and Foreign Specifications for Steel Castings*.' Part I. 10 × 8 in., pp.xiv + 48. Illustrated. 1959, Sheffield: The Association. (Price £2)

A guide to specifications for steel castings in Austria, Belgium, France, East and West Germany, Great Britain, Sweden, Switzerland, and the USA. In some instances comparable British Standard Specifications are given in summaries of specified requirements for each country. An appendix provides a summary of test piece dimensions. Part 2, to be issued at a later date, will include the Commonwealth, and countries not found in Part I.

Carter, C. F. and Williams, B. R. '*Science in Industry—Policy for Progress*.' 8½ × 5½ in., pp.ix + 186. Illustrated. 1959, London: Oxford University Press. (Price 21*s*.)

This book, by two professors of economics at Manchester University, is the third of a series of reports written by them for the Science and Industry Committee. The earlier studies, '*Industry and Technical Progress*', 1957, (reviewed *JISI*, January, 1958) and '*Investment in Innovation*', 1958 (*JISI*, December, 1958) surveyed the factors affecting the rate of application of new ideas in British industry. The first part of this report provides general suggestions for industry on such topics as the communication of technical information, the value and organization of research and development, and the economics of innovation. The second part (the order is said to be significant) deals with ways in which government can promote industrial progress. The report, as a whole, is a vigorous account of a subject which, in less skilled hands, can easily become a catalogue of trite maxims. A final chapter gives a 'summary of proposals' and provides page references to the more detailed discussions in the text. All these proposals are sound and, expressed as they have to be in general terms, few will take exception to them. A point to note is that the 'summary', actually an analytical table of contents, inevitably oversimplifies the problem and to some extent limits the significance of the proposals. Thus, it is not only within the firm that personal contact is often more effective than written communication in promoting the flow of technical information.—M. L. Pearl.

Codell, M. '*Analytical Chemistry of Titanium Metals and Compounds*.' Chemical Analysis series—IX. 9 × 6 in., pp.xiii + 378. Illustrated. 1959, London, New York: Interscience Publishers. (Price £4 10*s*.)

With the rapid growth of the titanium industry in the USA over the last eight years, there has been a wealth of effort in associated technology and this particular book reviews one aspect; the determination of titanium in titanium-rich materials and of the common alloying elements and impurities found in titanium alloys. The subject is introduced by a brief account of the chemistry of titanium and a discussion on the application of general separation procedures, emission spectrography, and vacuum fusion analysis in titanium. The alloying elements dealt with are Al, V, Ta, Nb, Cr, Mo, W, Mn, Fe, Sn, Co, Ni, Cu, Zr, Mg, Be, Ca, Na, Pb, Ag, Rare earths, H, C, Si, N, P, B. O, S, and Cl. For most purposes this list can be regarded as completely adequate. The analysis of titanium in $TiCl_4$, Ti-base pigments, minerals, ores, concentrates, and slags is also surveyed. There is little attempt to compare any of the techniques critically or to discuss fundamental aspects of the chemistry of titanium. The treatment of the subject is, therefore, one which will appeal more to the junior analytical chemist who is in search of a method.—H. C. Child.

Erickson, C. '*British Industrialists. Steel and Hosiery* 1850–1950'. 9 × 6¼ in., pp.xxi + 276. 1959, Cambridge: Cambridge University Press. (Price £2)

This survey of the social origins and career patterns of some 1000 active directors and senior managers in the steel and hosiery industries is an extremely thorough and painstaking piece of work. The object in studying two such dissimilar trades was to obtain information about social mobility and the influence of an industry's scale of capital investment upon management recruitment. Herself an American, Dr Erickson's findings may explode some misconceptions about 'typical' British and American top managers. While family influence remains more marked in British steel businesses (and in this and other respects private and public companies do not differ so greatly as may be thought), the proportion of leaders who have risen from the production departments within their own industry has been broadly similar on both sides of the Atlantic; today the British steel industry is recruiting to high office a greater proportion of technically or scientifically trained men than ever before. There are more marked differences as regards non-technical professional men: lawyers have always had a much stronger foothold in American business corporations, while qualified accountants in large British steel firms have established 'a firmer bureaucratic bridge to top office than any other professional group'—they comprised 10% of Britain's leading steel officials in 1953 and only 3% in all large American corporations (including railroads and public utilities). American officials are appointed to high office at an earlier average age; but they tend to have joined their firms younger and to have served in them longer than their British counterparts before reaching the top. Once there, more of them stay put until death or retirement.

The comprehensive chapter on 'The Introduction of New Techniques in Steel-Making', describing the early spread of the Bessemer and Siemens processes and the firms and the men who were first to adopt them, indicates that if Dr Erickson can spare time from her more sternly statistical sociological studies to write up some of the biographical material which she has unearthed, she could give us an authoritative volume on the lives and characters of many British Steelmakers.—A. E. G. Wright.

The International Union of Crystallography. '*International Tables for X-ray Crystallography*.' Edited by J. Kaspar and K. Lonsdale. Vol.II. 10¾ × 8 in., pp.xviii +

444. Illustrated. 1959, Birmingham: The Kynoch Press. (Price £5 15*s*.)

All students of crystal growth, form, and structure have been indebted to the editors of the first volume of this major work, which was published in 1952 and dealt with crystal symmetry and the crystallographic groups. Rapid methods of mechanical computation, techniques of crystal structures analysis, and application of X-ray crystallography have all developed a great deal since the appearance of the earlier volume and the publication of these splendidly produced mathematical tables is to be welcomed. A large number of authors have contributed to the present volume which is divided into sections dealing with Basic Mathematics, Crystal Geometry, Diffraction Geometry, Physics of Diffraction Methods, Fourier Synthesis and Structure Factors, Special Topics, and, Miscellaneous Exponential and Trigonometric Tables. A final section provides a Dictionary of Crystallographic Terms in English, French, German, Russian, and Spanish.

'*The Ironfoundry Handbook*.' 1st edition. $9\frac{3}{4}\times7\frac{1}{4}$ in., pp.xliii+293+96. Illustrated. 1959: London, The Standard Catalogue Co. Ltd. (Price £2 2*s*.)

This new Handbook provides a much needed directory of British ironfoundries. The work is divided into two main parts: one in which the firms are arranged by location in ten regions (including Eire); the other arranged by product under three headings—malleable iron castings, grey iron castings (divided into nine sections), and miscellaneous specialized castings. In addition, there are sections dealing with British Standard Specifications, brand names, and producers and suppliers of equipment. It would be useful in future editions to have a comprehensive alphabetical index of firms with cross references. At present, if the address of a firm is not known, the user has to search through ten regional lists although cross-references to the product section of the Handbook have been provided.

MILLER, G. L. '*Tantalum and Niobium*.' Metallurgy of the Rarer Metals series—6. $9\frac{1}{2}\times5\frac{1}{2}$ in., pp.xxii+767. Illustrated. 1959, London: Butterworths Scientific Publications. (Price £6)

This book is the latest of this well known series, and as in the case of the other volumes is an authoritative account of all the chemical and metallurgical characteristics of the elements concerned. The publishers have broken with precedent in this case however, by covering two elements in one volume and have been encouraged to do so because of the obvious similarity in the chemistry and metallurgy of Tantalum and Niobium. The resultant volume is somewhat long (759 pp) and costs £6 compared with £1 10*s*.—£3 10*s*. for the others of the series. From the cost aspect alone one wonders whether the speicalist might not have been better served by two separate volumes or some condensation of the presentation to enable publication to be achieved at a more modest price. The author, who has been personally connected with much of the experimentation and production of these metals, does however ensure that the publication justifies its high cost by the wealth of information he includes.

The subject is introduced by an account of the history and uses of the metals. As both metals have been used extensively as alloying elements this account has of necessity to cover heat resisting steels, hard metals, magnets, 'Tantung' alloys, and optical glass apart from the uses for the metal itself. The extraction metallurgy and the separation of two elements are dealt with in great detail and the author covers many potential processes only used in the laboratory as well as production techniques. The consolidation of the pure powders produced is by powder metallurgy which involves many modern developments such as high temperature sintering (>2000°C) *in vacuo* or the newer vacuum melting processes such as the electron beam or consumable arc techniques. The account of these processes is of considerable interest to workers in fields other than Ta or Nb. The technological aspect of the subject is completed by a review of the forming, welding, and machining characteristics. The remaining half of the book is devoted to the physical, mechanical, chemical, and alloying properties of the elements. In view of the restriction which the ready oxidation of these elements imposes on their use, it is appropriate that there is a lengthy consideration of reaction with gases.

Many readers of this book will be surprized at the wealth of information available on these two elements. One might therefore ask whether they can be regarded as 'rare'. It is perhaps fairer to acknowledge that the author has sought widely and successfully for his information and the reward of his labours is a most useful reference book.—H. C. CHILD.

RASSWEILER, G. M., and GRUBE, W. L. (Editors). '*Internal Stresses and Fatigue in Metals*'. Proceedings of the Symposium, Detroit and Warren, Mich., 1958. $9\frac{1}{2}\times6\frac{1}{2}$ in., pp.x+451. Illustrated. 1959, Amsterdam; London: Elsevier Publishing Company; D. van Nostrand Co. Ltd. (Price £3 12*s*.)

The continuous increase in speed, power, and temperature of power plant and machinery demands the development of new materials and a better understanding of the mechanisms of failure. Although essentially an engineering problem, this has attracted a large number of physicists mainly because of the structure-sensitivity of the processes of deformation and fracture. An unbridged gap still exists between the approach of the metal physicist and that of the engineer. This is therefore a field where inter-disciplinary activities are not only profitable but essential.

The book under review is the proceedings of a symposium organized by General Motors Research Laboratories and held in Warren, Michigan in 1958. Engineers and Metal Physicists were almost equally presented and the field covered ranged from observation of dislocations in iron whiskers to the effects of shot peening on fatigue strength. This divergence may have proved mutually beneficial to the scientists and engineers taking part in the meeting, but none of these benefits are passed on to the reader of the proceedings. The publication lacks the essential element in such an endeavour, namely a full recording of the discussions that followed presentation of the papers. Without this, the book is no more than a grouping together of some 25 papers, describing well-established conclusions. In fact a large proportion of the papers has already been published in almost exactly the same form. The appearance of the proceedings of this symposium does not appear to have served any useful purpose.—A. H. MELEKA.

SMIT, J., and WIJN, H. P. J. '*Ferrites; physical properties of ferrimagnetic oxides in relation to their technical applications*.' 9×6 in., pp.xiv+369. Illustrated. 1959, Eindhoven: Philips' Technical Library. (Price £3 12*s*.)

This book deals with the physical properties of magnetic ferrites. The sub-title is somewhat misleading as there is practically no reference to applications. The level is said to be 'Intermediate', but by page 7 the uses of vector analysis, relativity theory, and quantum mechanics have been invoked and the theoretical section is generally rather cumbersome.

The measurements section covers the assessment of magnetization, magneto-crystalline anisotropic energy, magneto-striction, complex initial permeability, and certain loss phenomena, particularly those associated with the dimensions of the specimen. A section on intrinsic properties of ferrites with different basic structures, viz. spinel, hexagonal, and garnet, is valuable in showing how magnetic properties are linked with atomic arrangement. Theoretical findings are confirmed by practical evidence to a greater extent than has been achieved with ferromagnetic metals. The final section on polycrystalline ferrites deals with the structure and electrical and magnetic properties of ferrite materials of various compositions made under different conditions. The treatment is rather academic and is not very helpful to potential users of commercially available materials.

As would be expected of a book on ferrites written by two members of Philips' Research team, there is much gold to be found in it; unfortunately the veins are often tortuous so that extraction becomes tedious. A list of mathematical symbols would have been helpful. The publishers and authors are to be congratulated on the clarity of type and reproduction of illustrations, especially some very good photomicrographs, including domain patterns made visible by the powder technique. The authors' claim that 'The book is intended for all those who are actively interested in the properties of ferromagnetic oxides' is well substantiated.—P. R. BARDELL

TAYLOR, H. F., FLEMINGS, M. C., and WULFF, J. '*Foundry Engineering*'. $8\frac{1}{2}\times5\frac{1}{2}$ in., pp.vii+407. Illustrated. 1959, New York, London: John Wiley & Sons Inc.; Chapman & Hall Ltd. (Price £3 18*s*.)

The authors, universally known in foundry circles as teachers and researchers, give the reader an insight into the teaching methods of that world-famous Department of Metallurgy at the Massachusetts Institute of Technology. This book fills exactly the requirements of a student of foundry technology not only in the USA, but also in this country. He will even appreciate temperatures recorded in degrees Centigrade as well as in degrees Fahrenheit. The text is concisely written in 'layman's language' and contains no difficult mathematics. Rule of thumb procedures, however, have no place in this book; everything is treated from fundamentals. Bernoulli's hydraulic equation certainly helps to explain the design of runners and risers.

The book has 13 chapters and 395 pages, each chapter being a complete section in itself. Not a single photograph—not even in black and white—is to be found but the text is yet adequately illustrated by delightful three-dimensional sketches, mostly so simple and self-explanatory as to be suitable for blackboard reproduction. Possibly from the educator's point of view, the problems posed at the end of each chapter are most useful. Following Chapter 11 on Sands, one reads, for example, 'Obtain a bag of used black sand from a local steel foundry. Simulate the various steps in a wet and dry reclaiming system as described . . . using pails, Gooch "funnels", coking ovens or Bunsen burners, etc. . . . try some ideas of your own—you might invent a better method.' The initiative required from a student for this type of practical work is presumably responsible for M.I.T.'s success in technology. The wider publicity for these methods in *Foundry Engineering* not only gives a student the 'feeling' for metal casting but 'getting down to fundamentals' appeals also to the thoughtful practical man.—R. V. RILEY.

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AKADEMIYA NAUK SSSR. Institut Metallurgii Imeni A. A. Baikova. [Academy of Sciences, USSR. A. A. Baikov Institute of Metal. lurgy.] '*Issledovaniya po Zharoprochnym Splavam*'. [Investigations into High-Temperature alloys.] In Russian. $10\frac{1}{2}\times6\frac{1}{2}$ in., pp.160. Illustrated. Moscow, 1956: The Academy. (Price 8 r. 50 k.)

ALÉGRE, R., *et al.* '*Études de Pyrometric Pratique*'. Préface de G. Ribaud. $9\frac{1}{2}\times6$ in., pp.231. Illustrated. Paris, 1959: Eyrolles; Gautier–Villars. (Price 3300 Fr.)

AMERICAN SOCIETY OF MECHANICAL ENGINEERS. BATTELLE MEMORIAL INSTITUTE.

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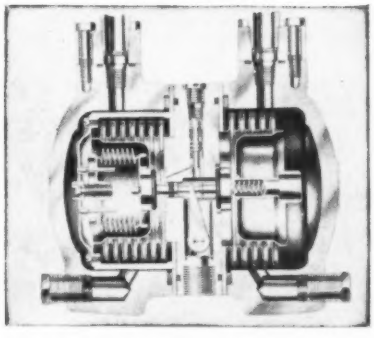

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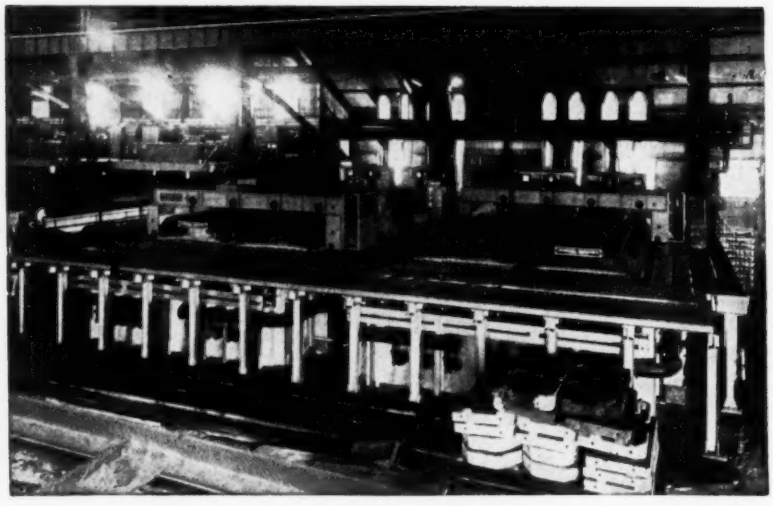

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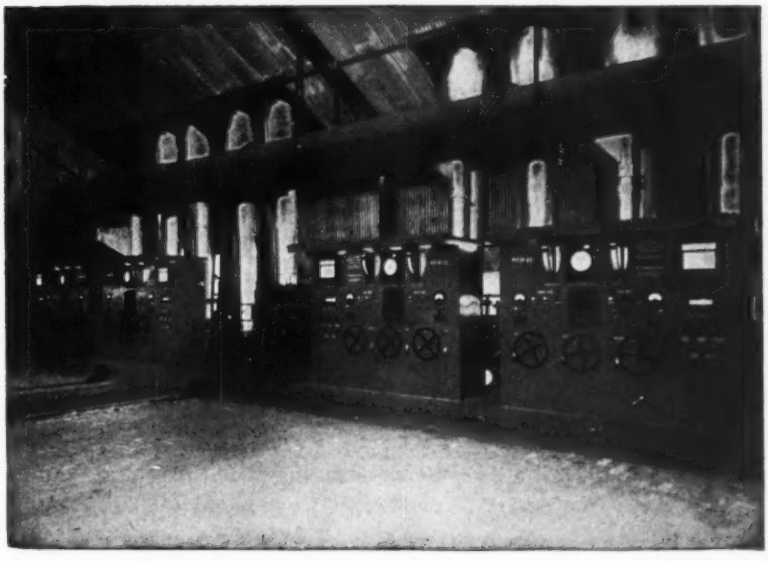

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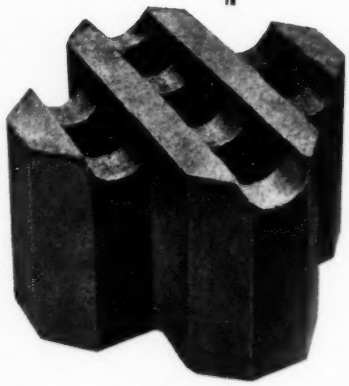

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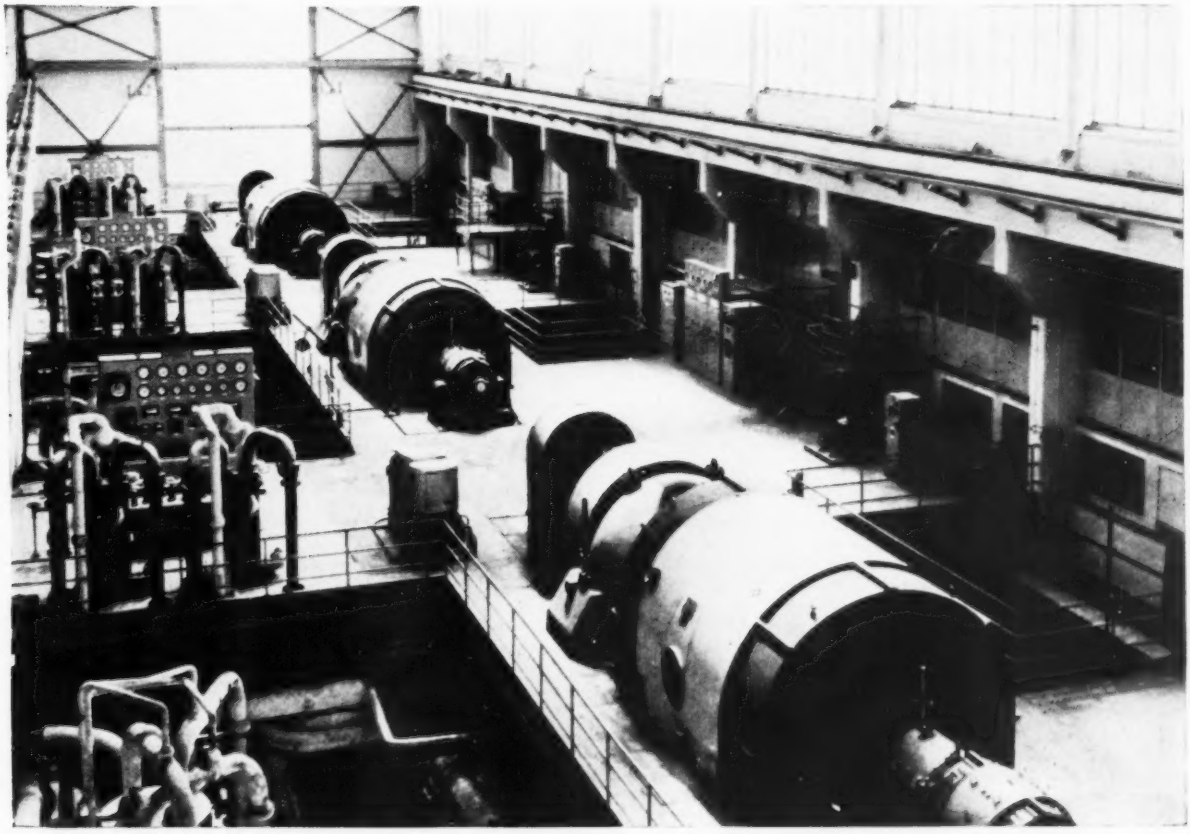

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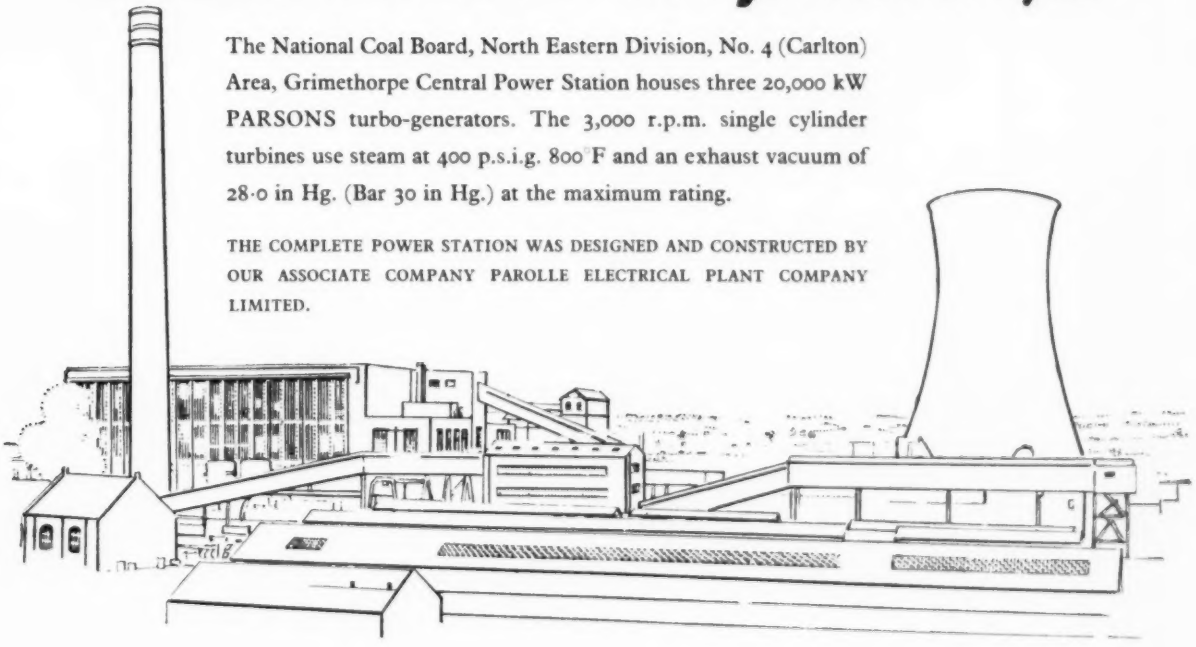

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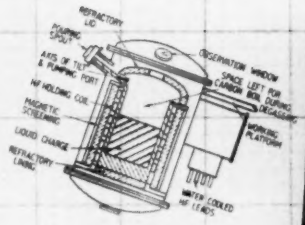

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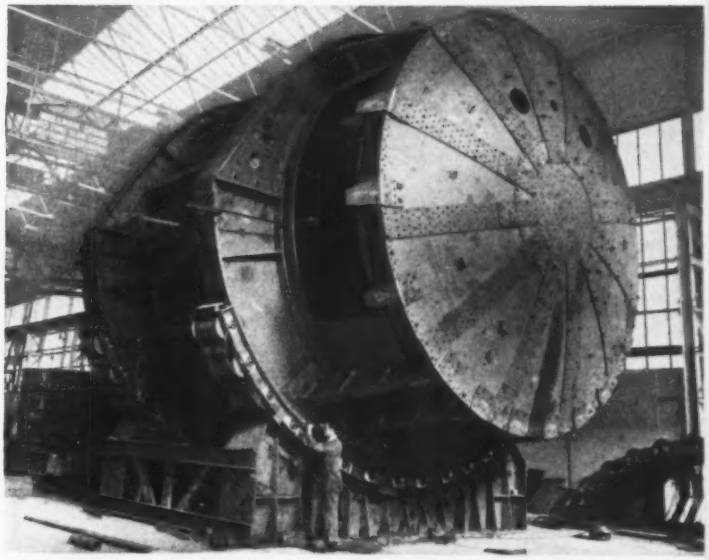

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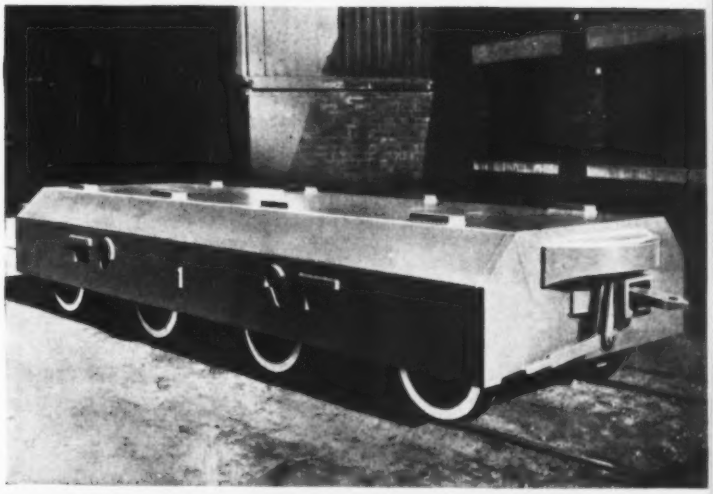

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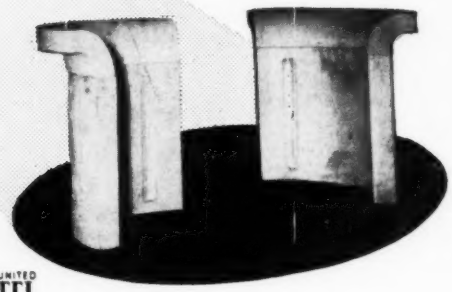

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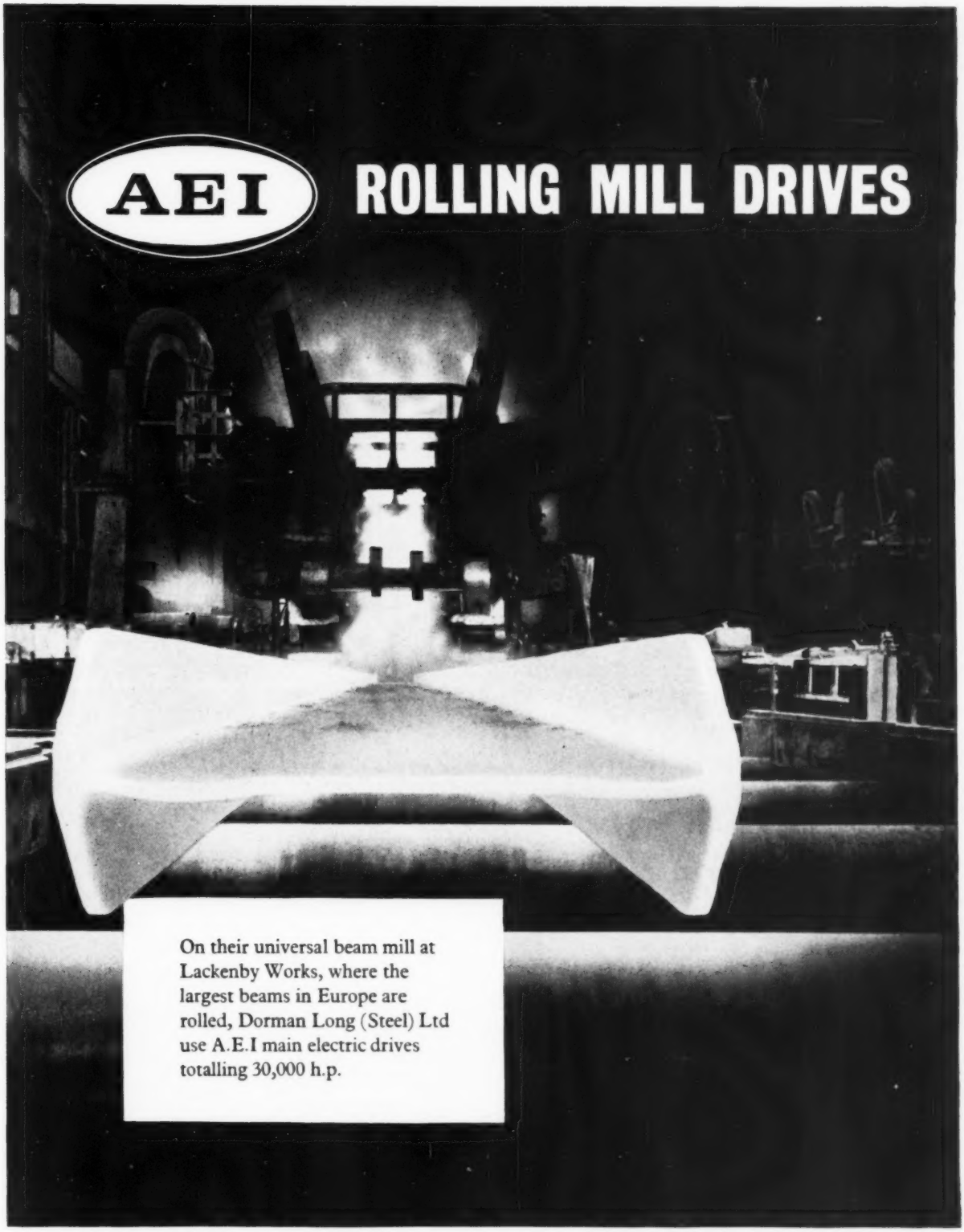
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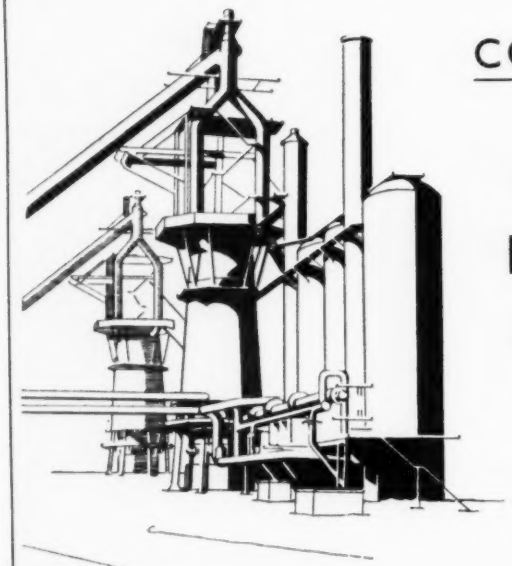

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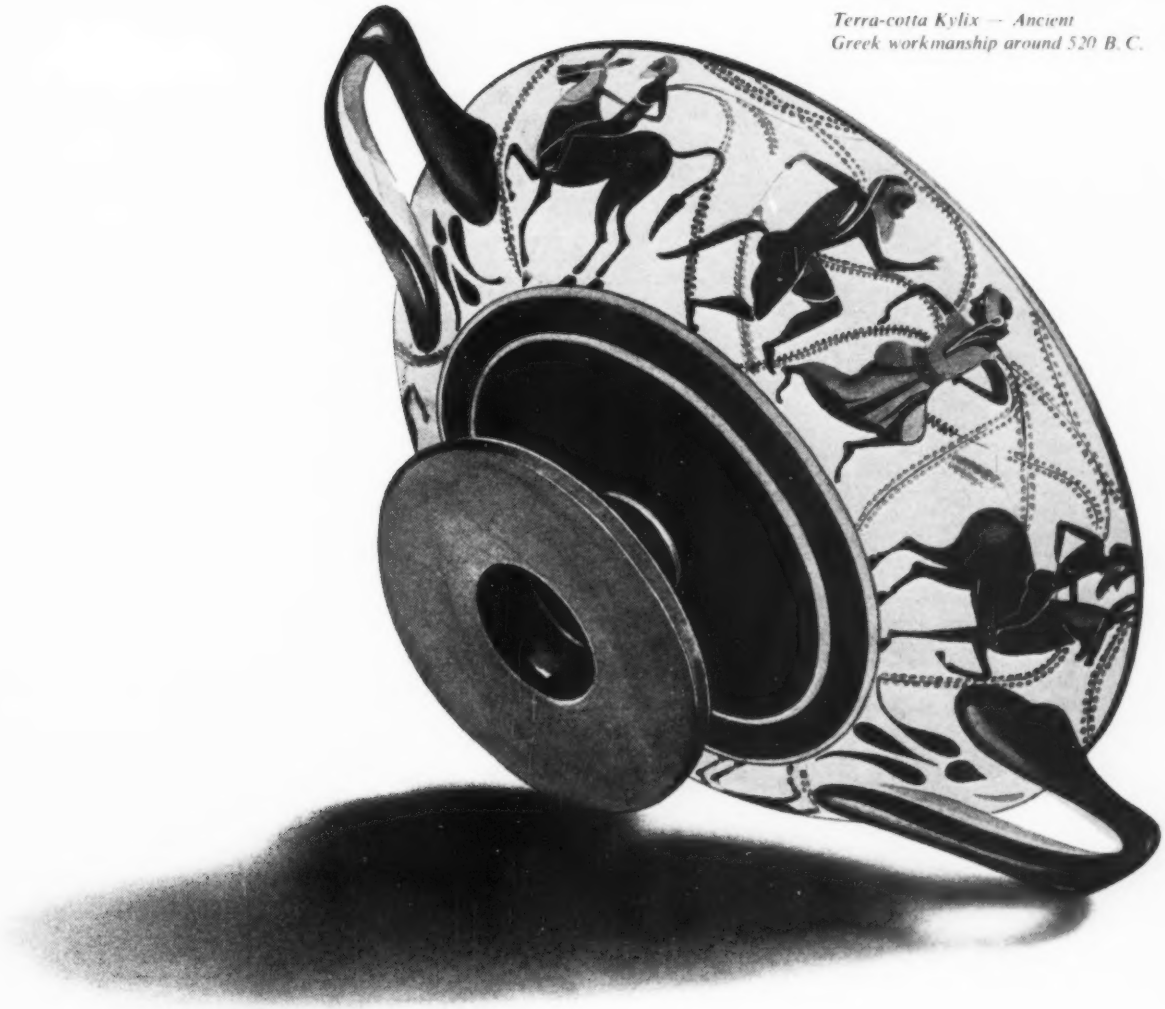

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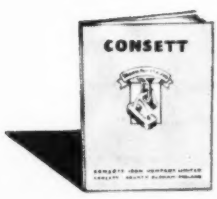

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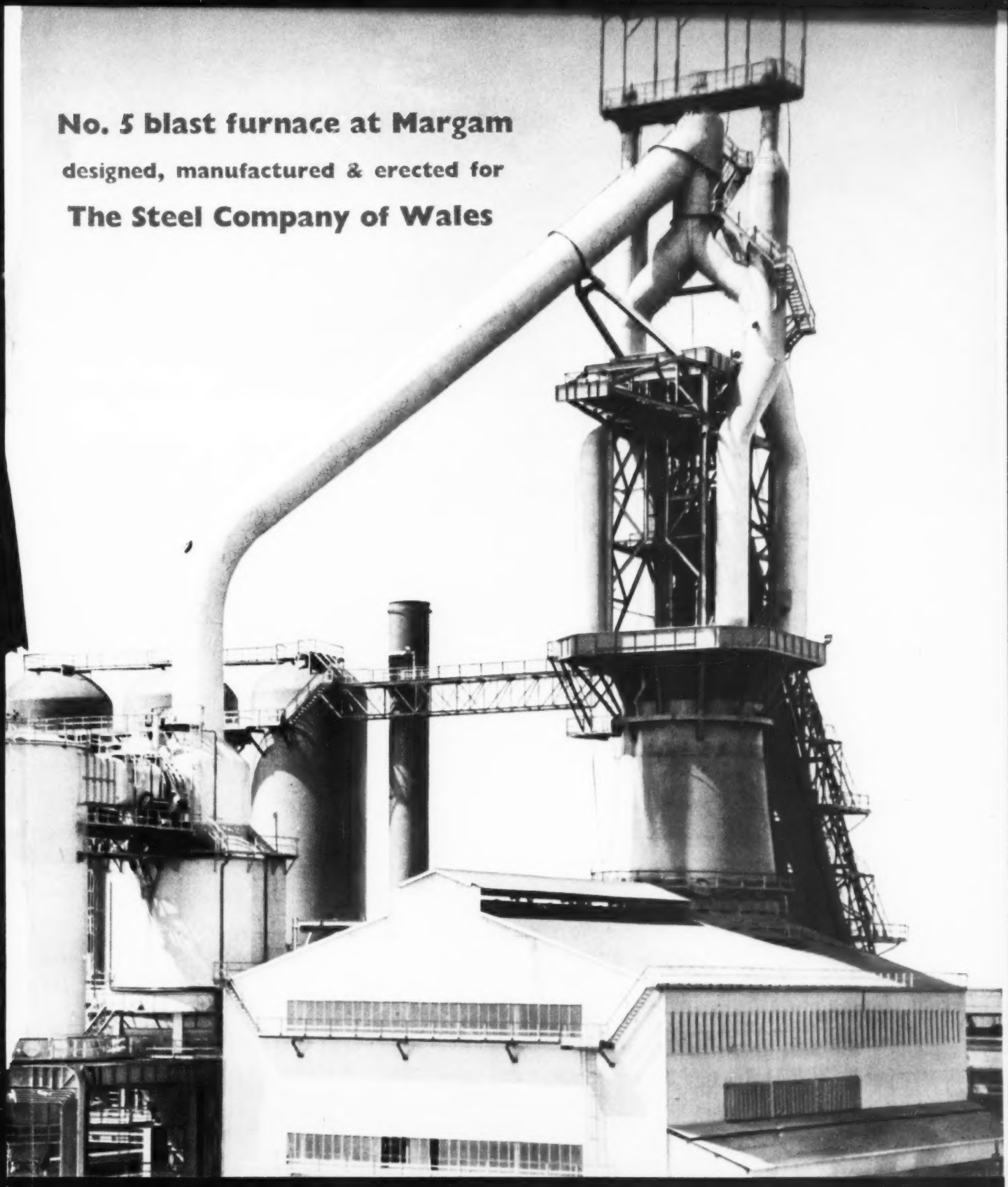

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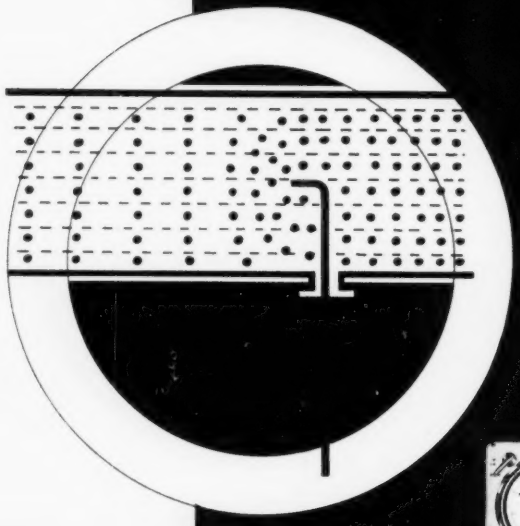

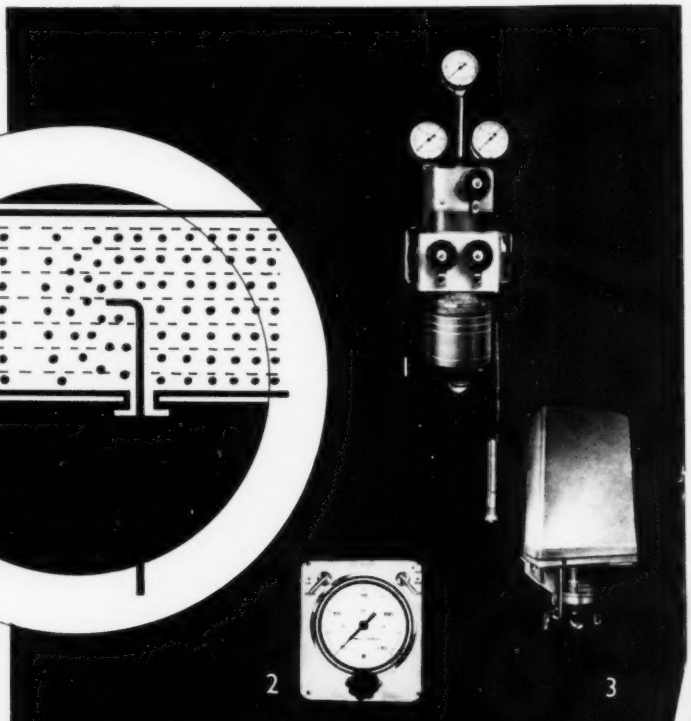

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